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Essentials of Medical Physics

Fred. J. Brockway, M. D.

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ESSENTIALS OF PHYSICS.

ARRANGED IN THE FORM OF

QUESTIONS AND ANSWERS.

PREPARED ESPECIALLY FOR

STUDENTS OF MEDICINE.

BY

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SECOND EDITION, REVISED.

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PREFACE.

In preparing medical students for examination in Physics, I have found Ganot too large to be used as a text-book. Some elementary books on the subject do not contain all that is necessary for the student to know.

I have here endeavored to compile a book which is a mean between these two extremes. It contains nothing original. With Dr. Chandler's kind permission I have made free use of notes upon his lectures delivered at the College of Physicians and Surgeons, New York. He is in no way responsible for my mistakes of statement or quotation.

Seventeen of the cuts have been reproduced from Gage's *Elements of Physics*, by the special permission of the author and the publishers, Messrs Ginn & Co.; eight cuts have been taken from Atkinson's *Dynamical Electricity*, by permission of the author and Van Nostrand Co., publishers; the other cuts are from Ganot's *Physics*.

New York, Dec., 1891.

PREFACE TO SECOND EDITION.

I AM indebted to Barker's *Physics* and Poyser's *Magnetism and Electricity* for much additional material used in this revision.

NEW YORK, Oct., 1893.

CONTENTS.

BOOK I.

ON MATTER AND ITS PROPERTIES.—SOLIDS, LIQUIDS, AND GASES.

BOOK II.

ON HEAT.

BOOK III.

ON LIGHT.

BOOK IV.

ON SOUND.

BOOK V.

ON MAGNETISM AND ELECTRICITY.

LIST OF ABBREVIATIONS.

Ag	is the chemical	symbol for	Silver.
AgCl	"	"	Silver chloride.
AgCN	"	"	Silver cyanide.
AgI	"	"	Silver iodide.
$AgNO_3$	"	"	Silver nitrate.
Al	"	"	Aluminium.
Al_2O_3	"	"	Aluminium oxide, or Alumina.
As	"	"	Arsenic.
As_2S_3	"	"	Arsenious sulphide, or Orpiment.
Au	"	"	Gold.
$AuCl_3$	"	"	Gold chloride.
Ba	"	"	Barium.
Bi	"	"	Bismuth.
Br	"	"	Bromine.
C	"	"	Carbon.
Ca	"	"	Calcium.
$CaCl_2$	"	"	Calcium chloride.
$CaSO_4$	"	"	Calcium sulphate.
Cd	"	"	Cadmium.
c. g.	is the abbreviation	of	Centre of gravity.
CH_2	is the chemical	symbol for	Methene.
CH_4	"	"	Methane, or Marsh gas.
C_2H_2	"	"	Ethine, or Acetylene.
C_2H_4	"	"	Ethene, or Olefiant gas.
C_xH_x	"	"	Indefinite number of atoms in a molecule of CH.
$C_{18}H_{30}O_{15}$	"	"	Cellulose.
$C_{18}H_{23}(NO_2)_7O_{15}$	"	"	Gun-cotton.
Cl	"	"	Chlorine.
CO	"	"	Carbon monoxide.
CO_2	"	"	Carbon dioxide, or Carbonic-acid gas.
Cr_2O_3	"	"	Chromic oxide.

$Cr_2(SO_4)_3$	is the chemical symbol for	Chromic sulphate.
Cu	" "	Copper.
$CuSO_4$	" "	Cupric sulphate.
E.M.F.	is the abbreviation of	Electro-motive force.
F	is the chemical symbol for	Fluorine.
Fe	" "	Iron.
Fe_2I_6	" "	Ferric iodide.
FeO	" "	Ferrous oxide.
Fe_2O_3	" "	Ferric oxide.
Fe_3O_4	" "	Ferroso-ferric oxide, or Magnetic oxide.
$FeSO_4$	" "	Ferrous sulphate, or Copperas.
$Fe_2(SO_4)_3$	" "	Ferric sulphate.
H	" "	Hydrogen.
HCl	" "	Hydrochloric acid.
H_2CrO_4	" "	Chromic acid.
Hg	" "	Mercury.
$HgCl_2$	" "	Corrosive sublimate.
Hg_2Cl_2	" "	Calomel.
HNO_3	" "	Nitric acid.
H_2O	" "	Water.
H_2O_2	" "	Hydrogen peroxide.
H_2S	" "	Hydrogen sulphide.
H_2SO_4	" "	Sulphuric acid.
I	" "	Iodine.
K	" "	Potassium.
KBr	" "	Potassium bromide.
KCN	" "	Potassium cyanide.
$K_2Cr_2O_7$	" "	Potassium bichromate.
KI	" "	Potassium iodide.
KNO_3	" "	Potassium nitrate.
K_2S	" "	Potassium sulphide.
Li	" "	Lithium.
Mg	" "	Magnesium.
MnO_2	" "	Manganese dioxide.
N	" "	Nitrogen.
Na	" "	Sodium.
NaCl	" "	Sodium chloride, or Common salt.
NaClO	" "	Sodium hypochlorite.
$Na_2Cr_2O_7$	" "	Sodium bichromate.
NaOH	" "	Sodium hydroxide, or Caustic soda.
Na_2S	" "	Sodium sulphide.

Na_2SO_4	is the chemical	symbol for	Sodium sulphate.
NH_3	"	"	Ammonia.
NH_4	"	"	Ammonium.
NH_4Cl	"	"	Ammonium chloride, or Sal ammoniac.
NH_4NO_3	"	"	Ammonium nitrate.
Ni	"	"	Nickel.
N_2O	"	"	Nitrous oxide, or "Laughing gas."
N_2O_2	"	"	Nitric oxide.
O	"	"	Oxygen.
O_2	"	"	One molecule of oxygen.
O_3	"	"	Ozone.
P	"	"	Phosphorus.
Pb	"	"	Lead.
PbO	"	"	Plumbic monoxide, or Litharge.
PbO_2	"	"	Plumbic dioxide.
Pb_3O_4	"	"	Plumbic tetroxide, or "Red lead."
$PbSO_4$	"	"	Plumbic sulphate.
Pt	"	"	Platinum.
S	"	"	Sulphur.
Sb	"	"	Antimony.
Sb_2S_3	"	"	Antimonious sulphide.
Se	"	"	Selenium.
Si	"	"	Silicon.
Sn	"	"	Tin.
SO_2	"	"	Sulphur dioxide.
Sp. gr.	is the abbreviation	of	Specific gravity.
T.	"	"	Temperature.
Zn	is the chemical	symbol for	Zinc.
$ZnCl_2$	"	"	Zinc chloride.
$ZnSO_4$	"	"	Zinc sulphate.

ESSENTIALS OF PHYSICS.

BOOK I.

MATTER AND ITS PROPERTIES: SOLIDS, LIQUIDS, AND GASES.

CHAPTER I.

MATTER AND ITS PROPERTIES.

What is Physics and its object?

Physics is that branch of science which treats of the transferences and transformations of energy. Its object is the study of the phenomena* of matter—those phenomena occurring upon the earth. Those outside the earth belong to the realm of astronomy. Chemistry deals with the permanent changes which affect the character and nature of matter, such as the decompositions of one body into another. Physics is the science of energy; chemistry, of matter.

What is matter?

Matter is that which reveals its properties to us by means of our senses; it is anything which occupies space. Matter and energy are inseparable, and constitute the physical universe.

What is energy?

Energy is the *capacity* for doing work. It is a condition of

* "Phenomenon," a happening or appearance.

matter in virtue of which a definite portion of matter can effect changes in other definite portions.

What are the kingdoms of matter?

There are three great kingdoms—*animal*, *vegetable*, and *mineral*. It is often difficult to draw a sharp line of distinction between them.

For example, marble is composed of the remains of little animals, the coral insects so called. If it is subjected to heat, we have—

$$\text{Marble}\begin{cases}\text{Fixed air} & \begin{cases}\text{Carbon,}\\ \text{Oxygen,}\end{cases}\\ \text{Quicklime} & \begin{cases}\text{Calcium,}\\ \text{Oxygen,}\end{cases}\end{cases}$$

carbon representing the vegetable, and calcium the mineral kingdom.

Describe and define elements and compounds.

The composition of matter has been determined by chemical analysis and synthesis. Should we grind a bit of marble into fine powder, the result would be marble still, fine particles of it, but each one capable of a chemical subdivision into C, Ca, and O. No one of these three has yet been further subdivided; no one has taken away from calcium anything but calcium.

The *elements* or *simple substances* are those which thus far have resisted all efforts to break them up into other substances.

The *compounds* are those substances which may be broken up into others.

We call the former "our elements," but it must be said they are probably compounds only awaiting some method by which they may be resolved.

Seventy or seventy-one elements are admitted, and many others have been proposed and will be.

Many lie in the chemical graveyard.

Five of our elements are usually gases—O, H, N, Cl, and F.
Two are liquids—Br and Hg.

All the others are solids.

The elements differ in color. Cobalt makes pink; nickel, apple-green; and iron, yellow solutions. Most of the metals have a same-

ness in color, yellowish-white, except Au, Cu, and Bi. There is also a great difference in their abundance. Oxygen composes $\frac{8}{9}$ of water, $\frac{1}{5}$ of the atmosphere, and $\frac{1}{2}$ of the earth's crust, which may be 8000 miles thick. All rocks are compounds of oxygen. We know something of the outer 50 miles of the earth's crust from the tilting of geological strata.

O *	constitutes	49.98%	of the	earth's crust.
Si	"	25.30%	"	"
Al	"	7.26%	"	"
Fe	"	5.08%	"	"
Ca	"	3.51%	"	"
Mg	"	2.50%	"	"
Na	"	2.28%	"	"
K	"	2.23%	"	"
H	"	.94%	"	"
		99.08%		

Titanium constitutes about $\frac{1}{3}$ of 1%, and a variety of others about $\frac{1}{100}$ of 1%. Earth weighs five or six times as much as water.

What are allotropic elements?

The same element may exist in different forms, and the uncommon one is called *allotropic*, which means the other kind or the strange kind; *e. g.*, ordinary oxygen and allotropic oxygen or ozone, O_2 and O_3. Phosphorus presents allotropic forms; so does carbon in graphite and diamond.

What are native elements?

Elements are usually combined in nature with others, but they may occur singly, as copper often does. They are then said to be native.

What are celestial elements?

Outside the earth, the sun, meteorites, and asteroids have all been analyzed, and they are found to possess "our elements," only in different combinations from those of earth. Such analyses are made by means of the spectroscope.

---

* This list also gives the order of frequency in nature of the first seven elements, if Fe and H be omitted.

What are the states of matter?

There are four—(1) solid; (2) liquid; (3) gaseous; (4) Crookes' state.

The first three are fairly represented by earth, water, and air; together with fire, the ancients called these "their elements." Their alchemy bloomed into chemistry only about one hundred years ago.

No one of the above states is peculiar to any substance. Whatever state a substance happens to have depends solely on temperature and pressure. All matter can appear as a solid, a liquid, or a gas, except carbon.

Every liquid has been solidified and volatilized. Every gas has been solidified and liquefied. Air was the last to surrender in 1878, when it was reduced to lumps.

Every solid has been vaporized, even C, but this alone refuses to be liquefied, simply because sufficient pressure cannot be used or no solvent found for it. If it could be liquefied, diamonds could be manufactured.

What are the characteristics of each state?

The distinctive character of *solids* is that the relative positions of their molecules are fixed and constant, and cannot be changed without the expenditure of some force. Hence solid bodies tend to retain whatever form may have been given them by nature or by art.

In the *liquid* state the relative position of the molecules is no longer fixed, but they glide past each other with ease, and the body assumes the form of any vessel in which it may be placed.

In *gases* there is still greater mobility of the molecules; they keep up an incessant struggle to occupy a greater space; so a gas has neither independent form nor independent volume.

The general term *fluid* is applied to both liquids and gases.

What is Crookes' state?

It is an ultra-gaseous state, or that in which the rarefaction of gases is pushed to its utmost, and is called *Crookes' vacuum.* Molecular actions, and not molar, come into play.

By aid of Sprengel's air-pump and chemical means a vacuum is

produced of $\frac{1}{3000000000}$ of an atmosphere. The experiments are carried on by means of a radiometer (Fig. 1). It consists of a glass bulb reduced to an extreme vacuum of air or any gas. The bulb contains on a pivot a vane of four radiating arms, each carrying a disc of mica blackened on one side. Due to the radiant action of heated or luminous bodies, very unusual phenomena of attractions and repulsions are seen. Bring a candle-flame near, and in a certain degree of vacuum the blackened sides of the discs are attracted, and the vane rotates toward the light: in a higher state of rarefaction the same sides are repelled.

FIG. 1.

This whole subject opens up an entirely new field for research.

Name the physical agents.

There are certain physical agents or natural forces which act upon matter—viz. *gravitation*, *heat*, *light*, *magnetism*, and *electricity*. The study of these practically comprehends the whole study of Physics.

What are the properties of matter?

There are *four general* properties, besides a number of *specific* properties due to molecular arrangement: (1) Impenetrability; (2) Extension or volume; (3) Figure or form; (4) Indestructibility.

(1) *Impenetrability* is the property of occupying space exclusively. When we drive a nail into wood, the iron and the wood do not occupy the same space at the same time. Strictly, it is the molecule which is impenetrable, though Ganot says atom.

(2) The *volume* of a body is that property by virtue of which it occupies a limited portion of space. Everything has volume, and

this, and impenetrability, are called the essential attributes of matter, since they are sufficient to define it.

Things with us are comparative: we must have standard units of comparison, especially for length, and the others follow. *Area* is space of two dimensions, and *volume* is space of three dimensions. The unit of volume is a cube, one edge of which is the unit of length, as the pint, quart, cubic centimetre, litre, etc.

What are the units in the metric system?

The metre is the foundation of this system, and the derivatives from the metre increase or decrease by 10 or multiples of 10.

The metre is about $\frac{1}{10000000}$ of the distance from the equator to the pole. According to law, it is the distance at 0° C. between two lines engraved on a platinum bar kept in the Paris Observatory. One one-hundredth of this, or 1 cm. (centimetre), is about $\frac{2}{5}$ of an inch. These are length units.

Units of volume and of weight are derived from them. The unit of volume is 1 litre: it contains 1000 c. c. (cubic centimetres).

The gram, gm., is the unit of weight: 1 c. c. of distilled water in vacuo at 4° C. weighs 1 gm.

In this system volumes and weights are mutually convertible, hence one of its advantages. One-half litre of water would mean 500 c. c., and would weigh 500 gm. By the English system $\frac{1}{2}$ quart of water would convey no idea of the cubic inches contained nor show any relation of weight.

1 metre = 39.37 inches.
1 centimetre = $\frac{2}{5}$ inches.
1000 c. c. = 1 litre = $\frac{9}{10}$ liquid quart.
1 c. c. of H_2O weighs 1 gram = 15.432 grains Troy.
1000 gm. = 1 kilogram = $2\frac{1}{5}$ lb. av.

It was once declared by law that a wine gallon should contain 231 cubic inches of distilled water, but the law did not mention the temperature. Modern science must be exact.

(3) *Figure* follows from the other two. It is the property by virtue of which matter takes a definite shape. The shape may be a fixed one, as with solids, or it may be dependent on the shape of the

containing vessel, as in case of liquids and gases. A gas can have no definite surface: we cannot have a vessel half full of a gas.

(4) *Indestructibility* has nothing to do with the other three. Matter cannot be destroyed, but may change its form or appearance. Man has not found the means by which matter can be created out of nothing or by which it can be reduced to nothing. It is a constant quantity. Every chemical change can be represented algebraically, and this puts chemistry upon a mathematical basis. When charcoal is burned nothing is lost.

$$\text{(Charcoal) } C + O_2 = CO_2.$$
$$12 + 32 = 44.$$

The same is true of wood or gunpowder.

$$\text{(Wood) } C_6H_{10}O_5 + 6O_2 = 6CO_2 + 5H_2O\,;$$
$$\text{(Gunpowder) } 3C + S + 2KNO_3 = 3CO_2 + K_2S + 2N.$$

With gunpowder there is an expansion of about 1 part into 275.

What is the atomic theory or hypothesis?

In old Grecian times there were two opposing schools in regard to the divisibility of matter, one of which held you could never reach a limit, and the other contended that hard atoms of different shapes and in rapid motion were the ultimate division.

John Dalton came out with the atomic hypothesis in 1807—called "hypothesis" because it is a doctrine founded on theory. This theory, and this alone, enables us to account for most of the phenomena of matter. Dalton's theory presupposes the existence of atoms, and is that of *definite proportions in chemical combinations, and that atoms have definite weights, called atomic weights.*

We know that matter can be found in extremely small quantities. We can detect the $\frac{1}{2000000000}$th of a grain of salt, and this is itself composed of two parts. Forty-one billions of little beings weigh a grain. Probably 40 definite chemical compounds exist in each. Fifteen hundred of them, placed end to end, would only reach across a pin's head. So we are familiar with many small subdivisions of matter without the aid of theory.

What are the divisions of matter?

Atoms, *molecules*, and *masses*.

What is an atom?

An atom is an indivisible particle of an element, or it is the smallest unit of matter recognized as existing. We could not have an atom of a compound. There are only about 70 different kinds of atoms, the combinations of which constitute the universe.

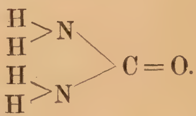
Atoms combine and form molecules, and these again unite and make masses.

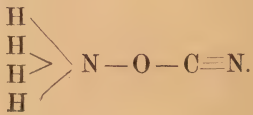
Atoms are usually found in groups, not going around alone, but Zn, Cd, Ba, and Hg may be found as single atoms, especially if in a state of gas. An atom of hydrogen does not weigh more than $\frac{1}{20000000000}$th of a grain. Atoms are supposed to be retained side by side without touching each other; neither are any two molecules of the universe in contact.

What is a molecule?

A molecule is the smallest part of any substance that can exist alone and exhibit the properties of that substance. It is a cluster of two or more atoms bound together by chemical affinity—*e. g.* a molecule of sugar contains 45 atoms, $C_{12}H_{22}O_{11}$: it is sweet and exhibits the properties of sugar. Molecules formed of different atoms are *compound; elementary* molecules have atoms of the same kind. There have been catalogued over 1600 organic compounds, and there is practically no limit. Molecules differ chemically in three ways:

1. Kind of atoms, HCl, AgI.
2. Number of atoms,  oxygen;  ozone; FeO, Fe_2O_3.
3. Arrangement.

CH_4N_2O is urea, 

NH_4CNO is ammonium cyanate, 

These two substances are *isomeric—i. e.* are composed of the same elements in the same proportion by weight, and yet form totally different bodies.

A molecule by itself could not be seen by the best microscope. Sir W. Thomson has calculated that if a drop of water could be magnified to the size of the earth, the water-molecules would then appear smaller than an apple. Each molecule is separated from its neighbor by inconceivably small spaces, and has a quivering motion, rebounding from its neighbors. When we heat a body we cause its molecules to move a little faster and to give harder knocks, and so to push away their neighbors a little; hence the increase in size of a heated body.

In solids the molecules are nearer each other than in liquids, and in liquids nearer than in gases. In solids their motion may be compared to that of a man in a dense crowd, where it is impossible for him to get out, but he may turn or move a little from side to side.

In liquids the motion may be like men moving through a crowd, and in gases like gnats in the air.

What is a mass?

A mass is a collection of molecules appreciable by the senses.

What is porosity?

From the fact that molecules have unoccupied spaces around them, it follows that masses have *pores.* They are of two kinds: 1. Visible or sensible; 2. Physical or intermolecular.

Only an imponderable ether can enter the intermolecular pores, giving the phenomena of heat or light. Sensible pores are little spaces between particles of the mass across which molecular forces cannot act. When water penetrates wood or mercury leaks through leather, it does it by entering these sensible pores. If the pores are of some size, we call them *holes.* All are illustrated in the sponge. Gold, chalk, lead, iron, are all porous.

What is real and apparent volume?

The *real* volume of a body is the space actually occupied by the matter of which it is composed.

The *apparent* volume is the real volume plus the total volume of its pores.

CHAPTER II.

THE ATTRACTIONS OF MATTER.

Distinguish chemical and physical changes.

There are chemical changes and physical changes; the former take place within the molecule and alter its character.

Physical changes take place outside the molecule, do not affect it, and therefore do not change the identity of the substance.

What is force?

Force is that which produces motion or pressure. "It is the measure of the tendency of energy to transform itself." A force is determined by knowing its place of application, its direction, and its magnitude.

What is the attraction or force controlling atoms?

It is *chemical affinity*, also called *chemism* and *atomic attraction*. It binds atoms together to form molecules, and is governed by circumstances: heat opposes it. It is sometimes very strong, as in SiO_2, quartz rock, or it may be very weak, as in NI_3, iodide of nitrogen, and in $HgC_2N_2O_2$, fulminate of mercury, substances which readily explode. HgO, mercuric oxide, is weak or strong according to temperature.

What are the forces controlling molecules?

(1) Cohesion; (2) Repulsion; (3) Polarity.

What is (1) cohesion?

Cohesion builds molecules into masses, and by its degrees or absence we have solids, liquids, or gases. It is greatest in solids, less in liquids, none in gases. If once this cohesion is overcome, it is difficult to force the molecules near enough together for it to become effective again. If, however, the two pieces, as of glass or iron, be heated, and then pressed together, the molecules will flow around each other and the surfaces adhere. This is called *welding.*

Name and describe some of the specific properties of matter.

The modifications of cohesive force give rise to certain special

conditions: such are *hardness*, *flexibility*, *elasticity*, *brittleness*, *viscosity*, *malleability*, *ductility*, *tenacity*, etc.

Hardness is the resistance which bodies offer to being scratched or worn by others. It is a relative property. Diamond scratches all, and is not scratched by any.

MOHR'S SCALE OF HARDNESS.

1. Talc;	4. Fluorspar;	8. Topaz;
2. Rock salt;	5. Apatite;	9. Corundum;
3. Calcite;	6. Feldspar;	10. Diamond.
	7. Quartz;	

Many bodies acquire great hardness by a sudden cooling after having been raised to a high temperature. This operation is called *tempering*. When glass is heated and slowly cooled it is rendered less brittle, and is said to be *annealed.*

What is elasticity?

Elasticity is that property by which bodies recover their former shape and volume after having yielded to some force. There is elasticity of traction, torsion, flexure, and pressure, according as the force pulls, twists, bends, or compresses. Liquids and gases are perfectly elastic. Solids are elastic up to a certain limit, which is called the *limit of perfect elasticity.* Beyond this point bodies either break or fail to regain their usual form and volume. Any alteration in the form of a body due to an applied force is called a *strain*, and the applied force is called the *stress.*

Brittle substances are those which break under a stress before there is any permanent alteration in their form.

Viscous substances are those which suffer a permanent change in form when subjected to a stress for a considerable time; *e. g.* a stick of sealing-wax with a weight suspended from its centre.

What is tenacity?

Tenacity is the resistance which a body offers to the total separation of its parts. It varies with the form of the body.

The quantity of matter being the same, a hollow cylinder has greater tenacity than a solid one, and the strength of this hollow cylinder is the greatest when the ratio of its external radius to its

internal radius is as 11 to 5. A cable is stronger than a chain of the same weight. The round, hollow stalk of grain is more resistant to the wind than a flat blade of grass.

Describe ductility and malleability.

Some substances seem to possess a certain amount of *fluidity; i.e.* their molecules may be displaced without overcoming their cohesion. When a solid possesses sufficient fluidity to allow of its being drawn out or pushed out into threads, it is said to be *ductile.*

Malleability is that form of ductility which is exhibited by hammering. The same substance does not usually possess these two properties to the same degree.

Platinum is the most ductile metal, but is only seventh in rank of malleability. Wollaston obtained a platinum wire $\frac{3}{100000}$ inch in diameter. Gold is the most malleable metal; it can be hammered so thin that 1800 sheets would only make a layer as thick as this printed page.

In order to be ductile and malleable a body must be tenacious, but not all tenacious bodies are ductile.

What is (2) repulsion?

Repulsion is the absence of cohesion, and is a property of gases. Their molecules are continually hitting and repelling each other. They resemble a coiled spring ready to relax as soon as pressure and confines are removed. Place an india-rubber bag partly filled with air under the receiver of an air-pump. As the vacuum increases the expanding air in the bag may burst it. Ordinarily, this internal pressure is exactly counterbalanced by an equal outside pressure of one atmosphere. Aëronauts sometimes forget this, and if they reach too great a height with a balloon filled with H gas, the outside air may be so rarefied, and the outside pressure be so removed, that the balloon will burst.

What is diffusion?

Many pairs of liquids do not mix with each other, but every gas mixes with or diffuses into every other gas, and it is impossible to prevent them if they are placed in contact. Owing to their property of repulsion they will not remain separated, a lighter resting on a heavier, as oil upon water, but they mix like alcohol and water.

There are many heresies in chemistry: there are no layers of carbonic-acid gas in a room, and no such thing as stratification of gases. If so, on the earth's surface would first come a layer of CO_2 about nine feet thick, destroying all animal and vegetable life. Next would come a layer of oxygen, and next nitrogen; then ammonia and other gases according to their specific gravities. We would have to take to the hills to prevent drowning from the noxious gases, and if we got too high we would have no oxygen.

What is (3) polarity?

Polarity * is that attraction of molecules which produces crystals. Dissolve sugar in boiling water and let it cool, and some of the sugar separates as crystals, called rock candy. The heat and solution destroy for a time cohesion and allow polarity to act.

Nearly all chemical substances crystallize into some geometric form in passing from a liquid to a solid state. It is not surprising that this new arrangement of molecules should occasion either an increase or a diminution in the volume of the mass. Water expands on solidifying, so do cast iron and type-metal; hence these metals can be cast in moulds.

Gold, silver, and copper contract on solidifying from a molten state, and so when used for coins they must be stamped.

What is amorphism?

The opposite condition of crystallization is amorphism: the arrangement of the molecules is without method or structure; *e. g.* in chalk, glue, charcoal.

What are the forces controlling masses?

(1) Adhesion; (2) Gravitation.

What is (1) adhesion?

Adhesion is a misused word, used differently by different authors. It is that force which binds together the *surfaces* of masses when in contact. Uniting surfaces, it can hardly be considered a molecular force.

Adhesion and cohesion run into each other. Adhesion may take place (*a*) between solids of like or unlike kinds; (*b*) between solids and liquids; (*c*) between solids and gases.

* Do not confound this polarity with the polarity of magnetism.

(*a*) Familiarly seen between two polished pieces of lead or glass. In case of glass the adhesion may be so strong that the pieces break before they separate. As this occurs in a vacuum, it cannot be due to atmospheric pressure. Glue and gelatin have wonderful adhesive powers, so strong that they can pull fragments of glass out of a solid plate. Without adhesion we could not pick up anything, driven nails would not hold their places, and buildings could not be erected.

(*b*) Kerosene oil is very adherent to solids, also water to solids. When we carefully raise a board from the surface of water without tilting, the force we overcome is not the adhesion of water to wood, but the cohesion of two layers of water, one of which remains on the under surface of the board.

If a liquid adheres to a solid more firmly than its molecules cohere, then the solid is *wet* by the liquid. Glass is wet by water or alcohol, but not by Hg, for in the latter case the cohesion of the Hg molecules is greater than their adhesion to the glass. But Hg wets lead and goes through it: a solid stick of lead can be used as a siphon for Hg.

A certain liquid will dissolve a certain solid only when the adhesion of the two is greater than the cohesion in the solid.

(*c*) If a glass plate be immersed in a liquid, bubbles will be seen to appear on its sides. They could not come from the pores of the plate, but from a layer of air which covered the plate before immersion.

This adherence of gases to solids is seen in electrical batteries or in the absorption of air and other gases by charcoal.

What is (2) gravitation?

Gravitation is the attraction of masses for each other, and is exerted on all matter at all distances. It is said to act at all distances greater than $\frac{1}{2000}$ of an inch, molecular forces acting at distances less than that.

The whole force with which two bodies attract each other is the sum of the attractions of their atoms or molecules.

Terrestrial gravitation is only a particular case of universal gravitation, often called *gravity* for short.

What are the laws of gravitation?

Sir Isaac Newton recognized these two laws:

(1) *The attraction between two material particles is inversely proportional to the square of their distances asunder.*

(2) *The attraction between two material particles is directly proportional to the products of their masses involved.*

Briefly expressed: *The attraction is inversely as the square of the distance and directly as the mass.*

(1) If the distances between two bodies be *increased* from 1 to 2, 3, or 4, the attraction would be *diminished* to the $\frac{1}{4}$, $\frac{1}{9}$, or $\frac{1}{16}$ part of its former intensity.

(2) Given two opposing bodies, and let the mass of one be doubled or tripled, the attraction between them will be doubled or tripled. If one mass be doubled and the other tripled, the distance remaining the same, then the attraction is six times as great as before.

The earth not only attracts the apple, but the apple also attracts the earth; it is mutual. There is great attraction between the moon and earth, so that tides of the ocean are produced from the force exerted by the moon, and the moon is kept within a certain orbit from the force exerted upon it by the earth.

The velocity of a person on the equator is about 1000 miles per hour, yet he does not fly off. Loose things on the earth's surface remain there, held by gravity.

There is no kind of matter which is opaque to gravitation (same is true for magnetism), neither does distance destroy it.

What is meant by the centre of gravity?

The centre of gravity (c. g.) of a body is a certain point through which the resultant of the attracting forces between the earth and its several molecules always passes. It may be within or without the body, according to its form. For many purposes the whole weight of a body may be supposed to be concentrated at its c. g., and in order to support a body it is only necessary to support this point.

The vertical line drawn through the c. g. is called the *line of direction.* Whether a body stands or falls depends upon whether or not its line of direction falls within its base. The Leaning Tower of Pisa continues to stand because this vertical line through its c. g. passes within its base.

To find the c. g. of any body is a purely geometrical problem. In regular figures with uniform density, as a circle, sphere, triangle, etc., it may be at once determined.

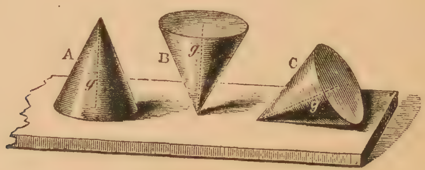
To find it experimentally, suspend the body by a string in two different positions, and the point where the directions of the string in the two experiments intersect is the c. g.

What are the three states of equilibrium?

A body always tends to assume a position such that its c. g. will be as low as possible; from this fact we may distinguish *stable*, *unstable*, and *neutral* equilibrium.

A body is in *stable* equilibrium if its condition is such that a disturbance would raise its c. g., in which event it would tend to resume its former position. It is in *unstable* equilibrium when a disturbance would lower its c. g.: it would not return to its former position. It is in *neutral* or *indifferent* equilibrium when it rests equally well in any position; *e. g.* a sphere.

FIG. 2.



Its c. g. is neither raised nor lowered by a change of base. In Fig. 2, A, B, and C illustrate in order these three varieties.

What does "up" and "down" mean?

These terms are derived from the attraction between the earth and terrestrial objects. "Down" is the direction a body takes moving in consequence of gravity, and it goes in a vertical or plumb* line. "Up" is the reverse direction.

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* "Plumb," from *plumbum*, because a piece of lead tied to a string is used to find this line.

What is weight?

Gravitation is the best measure for mass that we have. Mass means quantity of matter. Volume is not an efficient measure, as it varies with heat and density. The weight of a body means the numerical value of the mutual attraction between it and the earth.

There are arbitrary units. In weighing things the first law of gravitation in regard to distance is disregarded, and only the question of mass comes in.

A *balance* is simply a machine by which gravity is made use of to compare masses.

The unit of weight must be compared with a mass at the same place or altitude, and is for sea-level.

TABULAR RECAPITULATION.

Sciences.	*Divisions.*	*Controlling Forces and Attractions.*	*Physical Forces.*
Physics	Masses	Adhesion Gravitation	Mechanical power.
	Molecules	Cohesion Repulsion Polarity	Heat. Light. Magnetism. Electricity.
Chemistry	Atoms	Chemism.	——

CHAPTER III.

MATTER, FORCE, AND MOTION.

What are kinematics and dynamics?

Kinematics is the science of motion in the abstract. It deals with motion of translation, rotation, oscillation, and of elastic bodies.

Dynamics treats of force in the production of motion or pressure. Its subdivisions are *kinetics*, treating of force in producing motion, and *statics*, treating of force in preventing motion.

Describe motion and velocity.

Motion and rest are relative terms: there is no absolute rest in

the universe. Not only is there always motion of the mass as a whole, but motion of the molecules within it.

All motion takes time: hence the term *velocity*, which refers to the space traversed in a unit of time. Motion may be uniform or varied—*uniform* when an object traverses successively equal spaces in all equal intervals of time; *varied* when unequal spaces are traversed in equal intervals. Varied motion may also be accelerated or retarded.

State and apply Newton's First Law of Motion.

The relations between matter and force are expressed in Newton's Three Laws of Motion:

1st Law.—A body at rest remains at rest, and a body in motion moves with uniform velocity in a straight line, unless acted upon by some external force. This last fact is all that prevents perpetual motion.

A body cannot be isolated from such external forces as gravity, friction, and resistance of air.

What is inertia?

This first law covers a negative property of matter called inertia. Inertia is the inability of matter, of itself, to change its state of motion or of rest. We see practical illustrations of this daily. The athlete runs to the broad jump, so that the inertia of his body may aid his muscular efforts. The severest accidents on railway cars are chiefly due to inertia. The slow pressure of a finger will set a heavy door in motion; the sudden pressure of a pistol-ball will penetrate it without moving it.

What is the Second Law of Motion?

A given force has the same effect in producing motion, whether the body on which it acts is in motion or at rest—whether it is acted on by that force alone or by others at the same time.

What is the composition of forces?

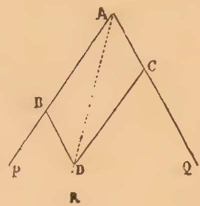
The problem of finding the *resultant* when the *components* are given is called the *composition of forces.*

Describe the method.

A force whose effect is equivalent to the combined effects of sev-

eral other forces is called their *resultant*, and the other forces are termed *components*. The resultant is found by means of the *parallelogram of forces*. The resultant of two forces acting at an angle to each other is always a diagonal of a parallelogram of which the components form two adjacent sides. In Fig. 3 let P and Q be two forces acting on the point A, and take A B and A C as representing their direction and magnitude. Complete A B D C, and draw the diagonal A D. This last line or single force R, acting along A D, is equal to the two forces P and Q acting along A B and A C.

FIG. 3.



What is resolution of forces?

Here we have given the resultant and one of the components, to find the other one. Construct a parallelogram as before, and the side starting from the junction of the two given lines will be the required component.

What is a couple?

Two equal parallel forces acting toward contrary parts constitute a couple: they produce rotation, and cannot be balanced by any single force whatever.

How is curvilinear motion produced?

When a body is once in motion, unless it is acted upon by some other force, it will move uniformly forward in a straight line with unchanged velocity. If, therefore, it moves in any other path, as a circle, it must be due to some force which continually deviates it.

In swinging a stone in a sling, if the string be cut or loosed, the stone will move off in a straight line, which is a tangent to the curve it was describing. The tension on the string which pulls the stone toward the centre of the circle and makes it describe a circular path is called the *centripetal* or centre-seeking force. The reaction of the stone on the string which is equal and opposite to the above force is the *centrifugal* or centre-fleeing force. This latter is made use of in laboratories to separate liquors from crystals, in sugar-factories to purify sugar of syrup, and in laundries to dry clothes. The centrif-

ugal force at the equator is greater than at the poles, and it tends to neutralize somewhat the force of gravity. From this cause it is calculated that a body weighs about $\frac{1}{289}$ less at the equator than at the poles.

Due to the flattening of the earth at the poles, the polar diameter being 26 miles shorter than the equatorial diameter, a body on the equator is farther away from the centre of the earth, and again weighs less by about $\frac{1}{590}$. $\frac{1}{289}+\frac{1}{590}=\frac{1}{194}$ less attraction at the equator than at the poles.

Describe accelerated motion.

The most familiar example is that of falling bodies. A single constant force like gravity, encountering no resistances, always has a uniformly accelerated motion: it causes the same increase during each subsequent unit. This value, called g, is found to be $9.8^{m.}$, or 32.1912 ft. for London.

A body in falling from rest starts with 0 velocity, and ends the first second with $9.8^{m.}$ velocity; consequently it would fall during that second only one half of $9.8^{m.}$, or $4.9^{m.}$, or $16\frac{1}{12}$ ft.

The velocity at the end of any second is $9.8^{m.}$ more than it was at the end of the last second; at the end of the second second it would be $2\times 9.8^{m.}=19.6^{m.}$, and so on. $V=g\,T$. The formula for space traversed is $S=\frac{1}{2}g\,T^2$. If a body falls for four seconds, its rate of speed at the end of the time will be $9.8^{m.}\times 4=39.2^{m.}$ per second. The distance fallen will be

$$\tfrac{1}{2}\times 9.8^{m.}\times 4^2=4.9^{m.}\times 16=78.4^{m.}$$

To roughly determine the depth of a well or the height of a cliff drop a pebble from the top and note the time until it strikes the bottom. Square the number of seconds noted and multiply by $\frac{1}{2}g$, which is 16 feet.

Does mass affect velocity in a falling body?

The velocity of a falling body is independent of its mass. It would seem that a heavy body should fall faster than a light one, but it does not. Galileo was the first to prove this.

Gravity attracts all matter alike, but the above is strictly true only in a vacuum.

There all bodies fall with equal velocities, and a stone of any weight will fall no faster than a feather.

What does a vibrating pendulum indicate?

The force that keeps the pendulum vibrating is gravity. Were it not for friction and resistance of air, it would never cease vibrating if once set in motion.

It is found that the time of vibration is inversely as the square root of the force of gravity; it is independent of the mass.

What is a seconds pendulum?

It is a simple pendulum, 39.13983 in. long, whose time of oscillation* at Greenwich is 1 sec. It must have a slightly different length at other places.

What is the Third Law of Motion?

To every action there is an equal and opposite reaction.

What is momentum?

Momentum means quantity of motion, and its numerical value is the product of the mass by the velocity. A large mass moving slowly has great momentum; so may a small mass have if it moves swiftly.

When the apple falls, the earth does not appear to rise toward the apple, but the momenta of the two are equal; only the motion of the earth is imperceptible, as its mass is so great, while the motion of the apple is considerable, as its mass is so little.

The explosion of powder in a gun produces opposite and equal reactions. The recoil of the gun, fortunately, has not the velocity that the bullet has, because its mass is so much greater, but its momentum equals that of the bullet.

What is a machine?

A machine is an apparatus by means of which power can be advantageously applied to resistance. The work applied to a machine is equal to the work done by the machine. No machine, therefore, creates or increases energy. Like a bank, it pays out no more than it receives—practically not as much, for the work done is divided

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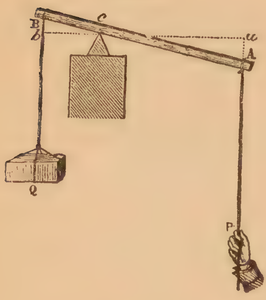
* One oscillation here means a single swing, and not a return. In speaking of sound, one vibration means a motion to *and* fro.

into two parts, a *useful* part or effective work, and a *wasted* part or internal work. This latter is transformed by friction into heat.

What is a lever?

A lever is any bar, straight or curved, resting on a fixed support called the *fulcrum*. The forces acting are the *weight*, W, or resistance, and the *power*, P.

FIG. 4.



The distances from the fulcrum to the points of application of P and W are called the *arms*. The relation of the power to the weight is the inverse ratio of their arms (Fig. 4). $P : Q :: cb : ca$. $P \times ca = Q \times cb$.

What kinds of levers are there?

Levers are divided into three classes, according to the position of the fulcrum.

In the *first kind* F (fulcrum) is between P and W, as in a poker or steelyard or in motions of the head.

In the *second kind* W is between F and P, as in a wheelbarrow, or the tendo Achillis in raising the weight of the body on the toes.

In the *third kind* P is between F and W, as in case of biceps attached to radius moving the forearm.

1st kind, P. F. W.;
2d " P. W. F.;
3d " W. P. F.

What is work?

When a force produces acceleration, or when it maintains motion unchanged in opposition to resistance, it is said to do *work*.

What are the units of work?

The unit of work in this country is the *foot-pound*, which means the quantity of work done in lifting 1 pound through a height of 1 foot.

This unit is not exactly invariable, since the weight of a pound, and therefore the work done in lifting it, differs at different places, being a little greater near the poles than near the equator. In the

metric system the *kilogrammetre* is the unit. It is the work done when the weight of 1 kilogram is raised through the height of 1 metre. It equals 7.24 foot-pounds, and 1 foot-pound equals .1381 kilogrammetre.

It will be noticed that these units have no relation to time, the work done being the same whether it is done slowly or quickly. But in estimating the usefulness of any motor time must be considered. The amount of work per second or minute is the *power* of a motor.

What is meant by horse-power?

In measuring the power of engines and the like the unit is a horse-power, which represents a rate of work of 33,000 foot-pounds per *minute*, or 4570 kgm. per minute.

What is the C. G. S. system and its units?

For measurements of force and work many use the C. G. S. system—*i. e.* centimetre, gram, and second—while others use the foot, pound, and second.

In the former the unit of force is called the *dyne;* that is a force which acting for a second will give to a gram of matter a velocity of 1 cm. per second. This unit is constant wherever we go on the earth or above it. The gravity unit of force is any unit of mass, a gram, pound, or ton, and is variable.

The unit of work is the *erg* (ἔργον), the work done by 1 dyne acting through the distance of 1 cm.

What is energy?

Energy is a condition of matter by which matter may do work; the quantity of energy that a body possesses is measured by the work it can do.

What is the difference between momentum and energy?

We have two measures of the effect of a force—momentum and energy. When mass remains constant, momentum is proportional to velocity, and energy is proportional to the square of the velocity.

In case of the bullet and gun the momenta of the two are equal, but the energy of the bullet is 133 times that of the gun.

Also, momentum may be found by multiplying the force by the *time* it acts, and energy by multiplying the force by the *space* through which it acts.

What are the two kinds of energy?

There is *potential*, or energy of position, and *kinetic*, or energy of motion. The former is possessed by a mass in consequence of work done upon it; a weight in falling may do work by turning a wheel; its potential energy becomes actual or kinetic.

The varieties of potential energy are *strain*, *gravitative separation*, *chemical*, *electrical*, and *magnetic separation;* of kinetic energy, *motion*, *vibration*, including sound, *radiation*, including light, *heat*, and *electricity* in current.

Thus all the phenomena with which physics deals are connected with energy, and physics considers matter simply as a vehicle of energy.

CHAPTER IV.

LIQUIDS.—HYDROSTATICS.

What is the province of hydrostatics?

Hydrostatics treats of the condition of equilibrium of liquids, and of the pressure they exert.

It has already been seen that liquids are bodies whose molecules are displaced by the slightest force. They are fluid, but to a less degree than gases. They practically know nothing of compressibility and are correspondingly inexpansible, while gases are eminently compressible and expand spontaneously.

For a long time it was thought that liquids could not be compressed. It is found, however, that water under a pressure of one atmosphere contracts 50 parts in a million. Air under the same circumstances contracts one half.

It would require 200,000 atmospheres to double the density of water; hence water at the bottom of the sea is not much more dense than upon the surface of the earth. To whatever compression a liquid may be subjected, it can be proven that there is an equal expansion; hence it is true that liquids are perfectly elastic.

What is Pascal's law?

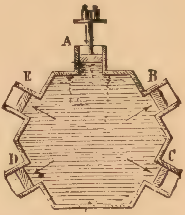
Pascal established a law for equality of pressures not due to action of gravity:

Pressure exerted anywhere upon a mass of liquid is transmitted

undiminished in all directions, and acts with the same force on all equal surfaces and in a direction at right angles to those surfaces.

Imagine a vessel with several equal-sized apertures, each fitted with a movable piston (Fig. 5). Upon A place a weight, say of 5 lb.; then a 5-lb. pressure will be transmitted to the face of each piston. Again, suppose this vessel have only two apertures, and let the area of A be 30 sq. in., and that of B 1 sq. in. Then if we place 2 lb. on B, it will require 60 lb. on A to maintain the equilibrium; a pressure of 2 lb. is transmitted to each of the 30 sq. in. of A.

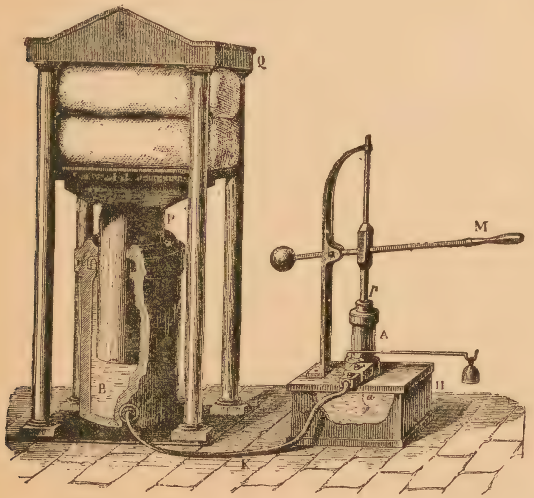
FIG. 5.



Describe the hydraulic press.

The application of this principle is seen in the hydraulic or hydrostatic press. The discovery of the principle is due to Pascal, but the

FIG. 6.



construction of the machine is ascribed to Bramah in 1796 (Fig. 6).

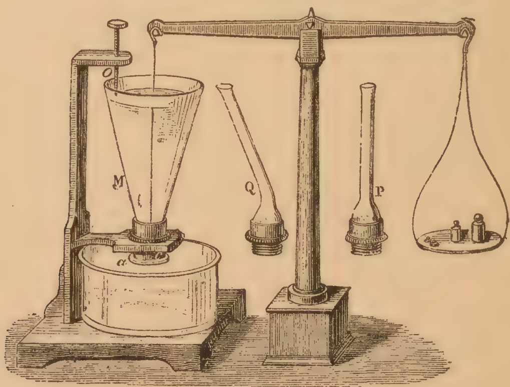
A is a suction- and force-pump connected by a lead pipe to the cylinder B. The pressure which can be exerted depends upon the relation between the surfaces of the pistons P and *p*. If P has a superficial area 100 times that of *p*, then the upward pressure on the large piston will be 100 times that upon the small one. A man might exert 60 lb. pressure on the end of the lever M, which from its length and position of fulcrum might be effective as 300 lb. on the small piston; then the force exerted on the bales to be pressed would be 30,000 lb.

Such a press is used in compressing paper, hay, or cotton, in extracting juices, bending iron plates, testing cables, etc. The principle finds many uses in opening dock-gates and in hotel or warehouse elevators.

Illustrate how liquids exert pressure by gravity.

Pressure exerted by a liquid in virtue of its own weight—*i. e.* by force of gravity alone—is *independent of the shape of the vessel and of the quantity of liquid, but depends on the depth and density of the liquid.* Take three vessels, M, P, Q (Fig. 7), of same depth and

FIG. 7.



same area at base, but of different capacities. Let a disc (*a*) attached by a string to a scale-beam serve as the base to M. Pour water into M, and note the depth of the water and the weights in

the scale-pan when the disc is forced off. Replace M by Q, and it will be found necessary to fill this vessel to the same height as the other one, with same weights in pan, before the disc drops. Same result will be found for P.

The fact that the pressure on the bottom of a vessel does not depend on the shape of the vessel, or even on the amount of liquid, is called the *hydrostatic paradox.* With a funnel-shaped vessel the pressure on the bottom is less than the weight of the contained liquid; with an inverted funnel-shaped vessel the pressure on the bottom is *greater* than the weight of the contained liquid.

How may a small amount of liquid produce great pressure?

Take a cask filled with water and fit a long tube into one end. If water be poured into the tube, there will be a pressure on the bottom of the cask equal to the weight of a column of water whose base is the bottom itself and whose height is that of the water in the tube; *i. e.* the pressure on the bottom is just as great as it would be if the sides of the cask had been continued up to equal the length of the tube and this whole cylinder filled.

Pascal succeeded in bursting a very solid cask by a narrow thread of water 40 feet high.

What is the hydrostatic bellows?

This apparatus consists of an air-tight vessel with leather sides, whose interior communicates with a small vertical tube. A person standing on the bellows can raise himself by filling the tube with water or even by blowing into the tube.

How is the equilibrium of liquids illustrated?

The surface of a liquid at rest is level, or, commonly expressed, we say, "Water seeks its lowest level." The principle is illustrated in the "water level" used by surveyors, in the spirit level used by carpenters, in the method of supplying water to cities, and in Artesian wells.

What is an Artesian well?

It takes its name from Artois in France, where these wells were first used, though perhaps they had been dug in Egypt and China in remote times.

The possibility of these wells depends upon the kind and direction of the strata of the earth: one permeable to water, as sand or gravel, should lie between two impermeable ones, as of clay. The rain falling on that part of the permeable layer which comes to the surface, called *outcrop*, filters through it along the tilting of the strata, and collects in the hollow of a basin confined by clay layers above and below.

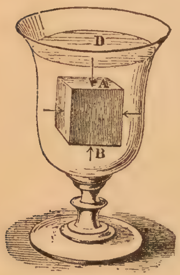
If a vertical hole be sunk down to this water-bearing stratum, the water, striving to regain the level of its source of supply, will either spout out of the well or rise in it a certain distance. London, Paris, and Vienna can get good Artesian water, as these cities are in basins. The strata under New York are nearly vertical; so wells here are not successful. One was bored to a depth of 3000 feet in St. Louis, without result.

What pressure is supported by a body immersed in a liquid?

If we slowly lower a piece of metal attached to a string into a vessel of water, we notice its weight gradually becomes less until it is completely submerged; on withdrawing it it seems to regain its former weight. In the water it seems as though something were pressing up against it. This lifting power is called the *buoyant force* of fluids.

When a solid is immersed in a liquid, every portion of its surface is submitted to a perpendicular pressure which increases with the depth. Let us imagine the cube A B immersed in water (Fig. 8). The pressures on the four vertical sides are evidently in equilibrium, so we will only consider the horizontal sides. The face A is pressed down by a column of water whose base is A and height is A D. The face B is pressed upward by a column of water whose base is B and height is B D ("pressure being transmitted undiminished in all directions."—*Pascal's Law*).

FIG. 8.



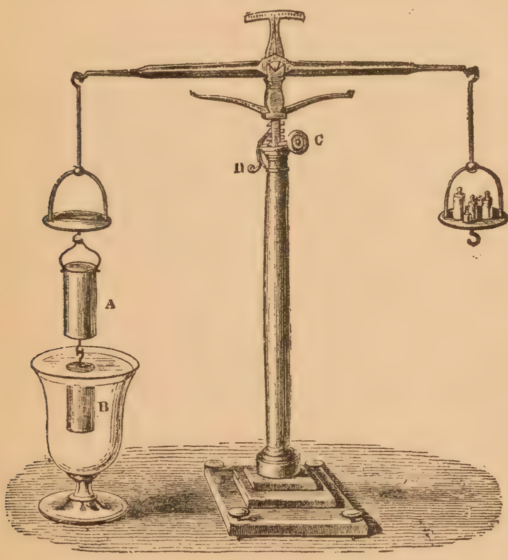
The whole solid, therefore, is pressed upward by a force equal to the difference between these two pressures, which is manifestly $BD - AD = AB$; *i. e.* it is the weight of a column of water having the same volume as the cube.

What is the principle of Archimedes?

The preceding discussion proves that every body immersed in a liquid is submitted to the action of two forces—viz. gravity, which tends to lower it, and buoyancy, which tends to raise it. The weight of the body is either partially or totally overcome by its buoyancy. Archimedes, a philosopher of Syracuse, discovered this principle in connection with Hiero's crown. It is generally expressed thus: *A body immersed in a liquid loses a part of its weight equal to the weight of the liquid displaced.*

This may be shown by the *hydrostatic balance* (Fig. 9). The beam being raised by the toothed rack, a hollow brass cylinder A is suspended from one of the pans, and below this a solid cylinder, B, whose volume is exactly equal to the capacity of A. First weigh them out of water, placing weights in the other pan. If now the

FIG. 9.



cylinder A be filled with water, the equilibrium is disturbed, but if at the same time the beam is lowered, so that B becomes immersed

in a vessel of water, the equilibrium is restored. B loses a portion of its weight equal to that of the water in A. But the capacity of A is exactly equal to the volume of B, proving the principle laid down.

How far will a floating body sink?

A floating body displaces its own weight of liquid, or it sinks until a buoyant force is reached equal to its own weight. If the liquid chance to be heavy and dense, of course the body does not have to sink so far in order to displace its weight as it would in a lighter liquid. Note the difference in the ease of swimming in salt and fresh water. The water of the Dead Sea is so salt (heavy) that a person cannot sink beneath its surface.

Define specific gravity.

Specific gravity (sp. gr.) *is the comparative weight of equal volumes.*

What is density?

Density means about the same thing: it is the weight of the *unit of volume*, so many grams to the cubic centimetre; sp. gr. states a numerical ratio. We say a big piece of cork is heavier than a bullet, yet we speak of cork as light and lead as heavy, knowing that cork is not so *dense* as lead; *i. e.* a given volume of cork contains less matter than an equal volume of lead. We can only express the density of a substance by stating two quantities—viz. weight or mass and volume. Density is weight divided by volume, $D = \frac{W}{V}$. If a piece of wood weighs 300 gm. and measures 400 c.c., $D = \frac{(W)\ 300}{(V)\ 400} = .75$ gm. per c.c. for the density of wood. Any two values of the above equation being given, we can always find the other one, $V = \frac{W}{D}$; $W = V \times D$.

How do you find the specific gravity of any solid?

Sp. gr., being the comparative weight of equal volumes, is that number which shows the relation between the weight of a certain volume of a substance and the weight of an equal volume of the

standard. Take two equal volumes, one of the substance and one of the standard; divide the weight of the former by the weight of the latter, and the quotient is the sp. gr. The weight of the standard is always the divisor:

$$\text{Sp. gr.} = \frac{W\text{, weight of 1 vol. of given substance}}{W'\text{, weight of 1 vol. of standard}}.$$

There is never any special difficulty in determining the numerator of this fraction. The trouble is with the denominator, as it is not always easy to measure and to get the exact volume of the given substance; and until we know that volume, of course we cannot get the "equal volume of the standard," which can then be weighed. A lump of metal full of holes and irregularities cannot be measured in any usual way. We could do this: Fill a vessel exactly full of water. Suspend a solid from a balance-beam and get its true weight. Remove from the balance, and carefully lower the solid into the water and catch the overflow. Weigh this displaced water, which of course is the exact counterpart in volume of the introduced solid. As water is one of the standards, this weight is the denominator of the above fraction, and the actual weight of the substance is the numerator.

This procedure, however, is not necessary, and the principle of Archimedes comes to our aid. There we saw that a body weighed in water loses a part of its weight, and this loss of weight is the weight of a volume of water equal to its own volume; and that is what we have been after for the denominator of the fraction, which fraction may now be stated thus:

$$\text{Sp. gr. of a solid} = \frac{\text{Weight of given substance in air}}{\text{Loss of weight of given substance in water}}.$$

Of course a fraction means that the numerator is to be "divided by" the denominator.

What are the three standards for determining specific gravity?

$$\text{For} \left.\begin{array}{c}\text{solids}\\ \text{and}\\ \text{liquids}\end{array}\right\} \text{distilled water} \left\{\begin{array}{l}\text{at } 60^\circ \text{ F. in England and America,}\\ \\ \text{at } 4^\circ \text{ C. in Germany and France.}\end{array}\right.$$

For gases and vapors: air (at 0° C. and 760 mm. pressure in France), and hydrogen.

Water, air, and hydrogen are the three standards.

Water weighs 62.5 lb. per cu. ft., or $8\frac{1}{3}$ lb. per gal., at standard temperature.

Air was originally the standard for gases and vapors, and is a convenient one, because we live in it. It is 14.42 times heavier than H. The sp. gr. of illuminating gas and some others are more conveniently expressed by the air unit.

Hydrogen, however, has many advantages. With it as a standard all the figures are whole numbers which bear a simple ratio, and also the sp. gr. can be found when formulæ and atomic weights are known. For instance, the sp. gr. of carbon dioxide is 22; *i. e.* is 22 times heavier than H, thus: CO_2 is the formula.

$$\begin{array}{l} C = 12 \text{ at. wt.} \\ O = 16 \\ O = \underline{16} \\ 2)\underline{44} \\ \quad 22 = \text{sp. gr. of } CO_2. \end{array}$$

Why do we divide by 2 in this problem?

What is Avogadro's law?

Equal volumes of all gases contain the same number of molecules. From which it follows that the molecules of all gaseous bodies are of the same size (not same weight).

Assuming that 1 vol. of H contains 1000 molecules, then, according to this law, an equal vol. of chlorine must also contain 1000 molecules. If these 2 vols. be mixed, they combine and form 2 vols. of another substance, hydrochloric acid gas, which will contain 2000 molecules. $\overset{1000}{H} + \overset{1000}{Cl} = \overset{2000}{HCl}$.

Upon analysis each molecule of HCl will be found to contain 1 atom of H and 1 atom of Cl—*i. e.* 2000 of each—but the 2000 H atoms came from the original 1000 H molecules, and the same for the Cl atoms. Each molecule of hydrogen must therefore have

furnished 2 H atoms, proving that the H molecule is made up of 2 atoms.

The atomic weight of H is taken as 1, hence its molecular weight is 2; and therefore we divide the weight of a molecule of CO_2, which is 44, by the weight of a molecule of H, which is 2, in order to reduce it to the standard of unity, comparing it with the H atom and not with the H molecule.

This applies to nearly all elements in a state of gas, and the sp. gr. of gases is one half the molecular weight. That is, gas molecules of an element are each formed of 2 atoms only.

There are five exceptions. Hg and Cd probably have 1 atom to the molecule in state of gas (perhaps also Zn and Ba); ozone has 3; P and As have 4.

Specific-Gravity Tables.

Solids, Water is standard.	
Li,	0.593
Na,	0.972
H_2O,	1.000
Mg,	1.75
Al,	2.56
Fe,	7.79
Ag,	10.50
Pb,	11.45
Au,	19.50
Pt,	21.50

Liquids, Water is standard.	
Ether,	0.720
Alcohol,	0.794
H_2O,	1.000
Urine,	1.020
Oil of vitriol,	1.840
Bromine,	2.976
Mercury,	13.59

Gases Illustrating the Two Standards.

Air = 1.	
H,	0.06929
N,	0.0972
O,	1.1056
CO_2,	1.524
Cl,	2.47
Br,	5.54
I,	8.716

H = 1.	
Air,	14.42
N,	14.
O,	15.96
CO_2,	22.
Cl,	34.98
Br,	80.
I,	127.

What are the three ways of finding the sp. gr. of solids?

1. Hydrostatic balance;
2. Nicholson's hydrometer;
3. Specific-gravity bottle or pyknometer.

1. *Hydrostatic Balance.*—The substance is first weighed in air; strictly it should be in vacuo. It is next suspended from the hook of the balance and weighed in distilled water at the standard temperature (Fig. 10). Divide the weight in air by the loss of weight in water, and the quotient is the sp. gr. required.

Example.

Zinc in air weighs	13.52 lb.	
" H_2O "	11.60 lb.	
Loss of weight in H_2O,	1.92 lb.	$\frac{13.52}{1.92} = 7.04$ sp. gr. of Zn.

To find the sp. gr. of a solid that floats in water; *e. g.* **wood.**

May use Nicholson's hydrometer, or attach a heavy substance like lead to the wood and sink it. Find the amount displaced by them both, then that displaced by the lead alone; subtract, and the remainder is the amount displaced by the wood. Suppose

The two solids lose in weight in water,	28.5
The lead loses " "	3.5
The wood would lose " "	25.
Suppose wood weighs in air,	20

$$\text{Sp. gr.} = \frac{20}{25} = .8.$$

Describe Nicholson's hydrometer and its use.

It consists of a hollow cylinder, B, to which is fixed a loaded cone, C (Fig. 11). At the top is a pan and a stem, on which the standard point *o* is marked. The first step is to ascertain the weight which must be placed in the pan to make the hydrometer sink to point *o*. Let such weight be 125 gr. Suppose the sp. gr. of sulphur be required. The weights are now removed from the pan and replaced by a piece of sulphur which weighs less than 125 gr. Add weights enough, say 55 gr., to depress the hydrometer to *o*. The weight of the sulphur is evidently $125 - 55 = 70$ gr.

Now ascertain the weight of an equal volume of water. To do

this place the sulphur on the lower pan C. The whole weight is not changed, yet the apparatus no longer sinks to the mark. The

FIG. 10.

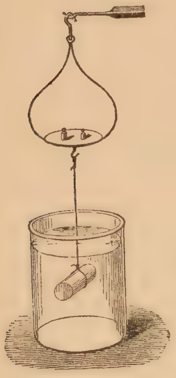
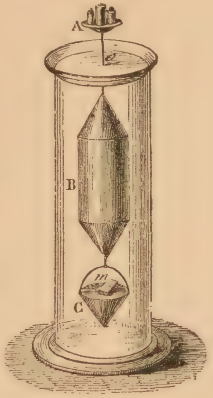


FIG. 11.



sulphur has lost part of its weight, equal to that of the water displaced. By added weights sink the stem to the standard again. This weight—34.4 gr., for example—is the weight of a volume of water equal to the volume of sulphur. Divide 70 gr., the weight in air, by 34.4 gr., and the quotient, 2.03, is the sp. gr.

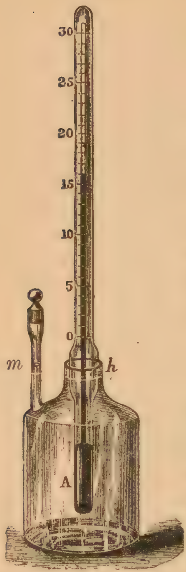
If the body is lighter than water, and will not remain on the lower pan C, adjust a cage of wire over it to prevent its ascent, and conduct the experiment as before. The water used must have the standard requirements.

Describe the specific-gravity bottle and its use.

This bottle is used for solids in a state of powder. Into the neck is fitted a thermometer A, and in the side is a capillary stem widened at the top and provided with a stopper (Fig. 12). On the stem is a mark *m*, and at each weighing the bottle is filled with distilled water at standard temperature exactly to this point.

Proceed thus: Weigh the powder in air. Then place it dry in a scale-pan, and with it, in the same pan, the sp.-gr. bottle exactly filled to the mark with water. Determine the weight of the two. Now

FIG. 12



empty the bottle, pour the powder into it, and fill as before to the standard point. Again determine their weight.

It is less than before, since the powder has displaced its own volume of water.

The difference between these last two weighings gives the weight of the water displaced, which, divided into the original weight of the powder, gives its sp. gr. The thermometer gives the temperature of the water and renders a correction easy.

How will you determine the sp. gr. of bodies soluble in water?

If the solid or powder is soluble in water, then we must use some liquid in which it is not soluble, as oil, naphtha, or kerosene, the sp. gr. of which is known. For rock salt we could use naphtha; for sugar, kerosene. The corrected sp. gr. is obtained by multiplying the answer found in the experiment by the known sp. gr. of the liquid used.

How do you obtain the specific gravity of liquids?

There are four ways:

(1) Hydrostatic balance;
(2) Specific-gravity bottle;
(3) Specific-gravity bulbs;
(4) Hydrometers.

(1) *Hydrostatic Balance.*—Have two vessels, one containing the fluid to be tested, and the other containing the standard water. Take some solid which will not be chemically acted upon by the liquid—*e. g.* platinum—and weigh it successively in air, in the liquid, and in the water. The loss of weights in the liquids is noted. They represent, of course, the weights of equal volumes of the given liquid and of water. Divide the former by the latter.

Find the sp. gr. of alcohol:

A piece of platinum weighs in air,		56.80
" " "	alcohol,	40.96
Loss in alcohol,		15.84

A piece of platinum weighs in air,		56.80
" " "	water,	36.80
Loss in water,		20.

A certain volume of alcohol weighs 15.84. The same volume of water weighs 20. $\frac{15.84}{20} = .792$ sp. gr. of alcohol.

(2) *Specific-Gravity Bottle.*—Weigh it first empty, then full of the liquid whose sp. gr. is to be determined, then full of water. Subtract the weight of the empty bottle respectively from that of the bottle plus the liquid, from that of the bottle plus the water, and thus get weights of equal volumes. Obtain the sp. gr. by division.

Example.

Bottle full of urine weighs	151 gr.
Bottle empty weighs	100 gr.
1 vol. of urine weighs	51 gr.

Bottle full of water weighs	150 gr.	Sp. gr. urine $= \frac{51}{50} = 1.020$.
Bottle empty weighs	100 gr.	
1 vol. of water weighs	50 gr.	

(3) *Specific-Gravity Bulbs.*—These are small hollow glass bulbs which are prepared in series, loaded, and adjusted so that they exactly float in a liquid of a definite sp. gr. Try each one with the given liquid till the right one is found, which is so marked as to indicate the sp. gr. without calculation.

(4) *Hydrometers.*—There are two kinds:

(*a*) Hydrometers of constant immersion, but variable weight.
(*b*) " of variable " but constant "

Hydrometers can only be used in liquids in which they float. They sink till they displace their own weight, and depend upon the principle of Archimedes.

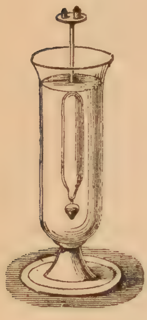
Of the first variety there are two examples—Nicholson's and Fah-

renheit's (Figs. 11 and 13). They are of constant volume, because always immersed to the same extent, but carry variable weight.

Describe Fahrenheit's hydrometer.

It is similar to Nicholson's, but is made of glass, and at its lower extremity is a bulb containing Hg. There is a standard mark on the stem (Fig. 13).

FIG. 13.



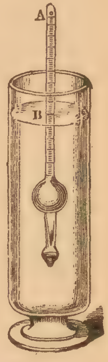
The instrument is first weighed in air, and then placed in the given liquid. Weights are added to the scale-pan, say 8 gm., until the mark on the stem is level with the surface of the liquid. In the same manner it is placed in water and weighted down, say by 6 gm., to the standard point. An equal volume is submerged each time. A floating body displaces its own weight of liquid, from which it follows that the weight of the hydrometer plus the weights in the scale-pan in the two cases is the weight of equal volumes of displaced liquid and of displaced water. Divide the former by the latter.

Describe hydrometers of variable immersion, but constant weight.

This variety includes *urinometers* and Beaumé's hydrometer and its modifications. They sink to variable depths according to the sp. gr. of the liquid, but their weight is constant. A simple hydrometer can be made from a rod of wood. Let one end be loaded, and assume its weight to be 50 gm. and its volume or cubical contents to be 100 c.c. How far will it sink in water? Until it has displaced 50 gm. of water, its own weight. What is the size of 50 gm. of water? 50 c.c., as each cubic centimetre weighs 1 gram, or $V = \frac{W}{D} = \frac{50}{1} = 50$ c.c., density of water being unity. So the 100 c.c. rod in displacing 50 c.c. of water would sink just half way. It would sink deeper in alcohol before it could displace its own weight, alcohol being lighter than water. Say 62.5 c.c. would be submerged —*i. e.* 62.5 c.c. of alcohol weigh as much as 50 c.c. of water, or 1 c.c. as much as $\frac{5}{6}$ c.c. of water. Sp. gr. of alcohol $= \frac{50}{62.5} = .800$, the sp. gr. being inversely as the volume when weight is constant.

Instead of a rod of wood, the usual hydrometer or urinometer consists of a graduated glass tube terminating at the bottom in a bulb loaded with shot or Hg (Fig. 14). The graduations indicate the sp. gr. These spaces are larger near the top, and are arranged according to the differences of the reciprocals of an arithmetical series. The sp. gr. values corresponding to these wide spaces are small, and increase from above downward, the instrument sinking deeply in light liquids, and *vice versâ*.

FIG. 14.



Reciprocals.	Differences in Reciprocals.	Sp. gr.
2.000	1.82	.50
1.818	1.51	.55
1.667	1.29	.60
——	——	——
.526	.015	1.90
.513	.013	1.95
.500	.013	2.00

Describe Beaumé's hydrometer and modifications.

Beaumé's hydrometer, alcoholometers, vinometers, salimeters, and lactometers express percentages, and not sp. gr. The graduation of Beaumé's depends upon the liquid used, and whether it is heavier or lighter than water; it is entirely conventional, neither giving the densities of the liquids nor the quantities dissolved. It is useful in making mixtures of given proportions; for instance, if 66° B. is the standard for oil of vitriol, a manufacturer can readily judge when his product has reached a proper degree of concentration.

One way of graduation is to construct the hydrometer so that it sinks nearly to its top in water, and call this point 0°, as at A, Fig. 14. Next place it in a 15 per cent. salt solution, and call the point at the surface of the liquid 15°, as at B. Divide the space A B into 15 equal parts, and so continue the scale to the bottom of the stem. Beaumé thought he could get percentages of any solution, but he cannot.

Tweddell's hydrometer, used in England, is so graduated that the number of degrees multiplied by 5 and added to 1000 gives the sp.

gr. with reference to water at 1000. Thus, 10° would equal sp. gr. 1050.

Alcoholometers are graduated for a certain temperature, and are only correct for that one, usually 15° C.

Lactometers also give percentages, but they can readily be changed to sp. gr. by aid of a table. 0° is marked at the upper end of the stem, and 120° at the lower end.

0° = sp. gr. 1.000;
10° = " 1.0029;
100° = " 1.029;
120° = " 1.0348.

The sp. gr. of milk should be 1029 or higher. No healthy cow gives milk below 1029 nor above 1040. Rich milk is not that rich in fats, but poor in water. This instrument is the milkman's foe.

Problems.—1. A gallon of water weighs $8\frac{1}{3}$ lb. av.; what is the weight of a gal. of Hg, its sp. gr. being 13.6?

Solution.—13.6 means that 1 vol. of Hg is 13.6 times heavier than the same vol. of water. If 1 gal. of water weighs $8\frac{1}{3}$ lb., 1 gal. of Hg will weigh $8\frac{1}{3} \times 13.6 = 113.33$ lb. Ans.

2. What is the weight of 1 gal. of alcohol, sp. gr. .800, when 1 gal. of water weighs 8.33 lb?

Solution.—$8.33 \times .800 = 6.66$ lb. Ans.

3. When 1 gal. of water weighs 58318 gr., what is the weight
 (*a*) of 1 gal. of urine, sp. gr. 1.030?
 (*b*) of 1 pint of ether, sp. gr. .720?

Solution.—(*a*) $58318 \times 1.030 = 60067.54$ gr. Ans.
 (*b*) The pint of ether must be compared with 1 pint of water, which would weigh $58318 \div 8 = 7289.75$ gr.
 $7289.75 \times .720 = 5248.62$ gr. Ans.

How do you find the specific gravity of gases?

1. Principle of specific-gravity bottle;
2. Divide weight of molecule by 2—*law of Avogadro;*
3. By rates of diffusion.

1. A glass globe is used of about 2 gallons capacity, and neck

provided with a stopcock. This method uses the air unit. Both the gas to be tested and the air are taken at 0° C. and at the pressure of sea-level, 760 mm.

The globe is first weighed empty—*i. e.* after a vacuum has been produced by an air-pump. Then it is weighed when full of the gas, and also when full of air. Both the gas and air must be passed through drying tubes, and the air over potash to free it of CO_2. Subtract the weight of the exhausted globe from the weight of the globes filled respectively with gas and air. Divide the former by the latter.

2. *The law of Avogadro* has already been discussed, pp. 48, 49. Methods (2) and (3) use the H unit.

3. *Rates of Diffusion.*—The following law has been established by Graham: *The velocity of the diffusion of any gas is inversely proportional to the square root of its density.* This follows from the size and velocity of repulsion of different molecules. If one weighs 16 times as much as another, then the latter has to move 4 times as fast to strike the same effective blow.

Density.	Diffusion rate.
H = 1	H = 4
O = 16	O = 1

The rate is inversely as the square root of 1 and 16. H, a light gas, diffuses 4 times as fast as O, a heavy one. We get the sp. gr. by noting the difference in times in which a given gas and H gas as a standard will diffuse from a capillary opening into air, or will *effuse* into a vacuum.

Summary of Methods of Finding Specific Gravity.

Solids (*a*) heavier than water:

Water standard.
- (1) Hydrostatic balance;
- (2) Nicholson's hydrometer;
- (3) Specific-gravity bottle (pyknometer).

(*b*) lighter than water:
- (1) Hydrostatic balance; attach a weight to the solid;
- (2) Nicholson's hydrometer with wire cage.

(*c*) soluble in water:

Use an indifferent liquid, as oil or naphtha, and hydrostatic balance. Multiply result by the known sp. gr. of the liquid used.

Liquids:

Water standard.
(1) Hydrostatic balance;
(2) Specific-gravity bottle;
(3) Specific-gravity bulbs;
(4) Hydrometers:

(4) (*a*) of constant immersion, but variable weight—Fahrenheit's;

(*b*) of var. imm., but const. wt.
some give sp. gr., urinometer;
some give per cent., Beaumé, alcoholometer, lactometer, etc.

Gases:

Air standard. (1) Principle of specific-gravity bottle.

H standard.
(2) Divide weight of molecule by 2—*law of Avogadro.*
(3) Rates of diffusion.

CHAPTER V.

CAPILLARITY.—OSMOSE.

Describe capillarity.

When solid bodies are placed in contact with liquids, certain *capillary* phenomena are seen, so called because best observed in tubes of a size comparable to a hair. The force in action is called capillary attraction. If we thrust a glass rod into a liquid which wets it, as water, the liquid is raised up against the sides of the solid as though not subject to the laws of gravity, and its surface is slightly concave (Fig. 15). Put the rod into Hg, which does not moisten it, and the liquid is depressed and its surface is convex. In the former case the adhesion of the glass and water is greater than the cohesion among the water molecules; the reverse is true for Hg and glass.

Instead of using a rod, take tubes of different diameters. The surface of the liquid in the tube when it wets it assumes a concave

FIG. 15.

FIG. 16.

FIG. 17.

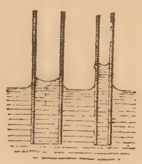


FIG. 18.

hemispherical segment called a *concave meniscus* (Fig. 17). When the tube is not moistened there is a *convex meniscus* (Fig. 18).

What are the laws of capillarity?

We may formulate these phenomena, and note four facts:

1. *Liquids rise in tubes when they wet them, and are depressed when they do not.*

2. *The ascension or depression is greater the smaller the diameter of the tube* (Jurin's law).

3. *The ascension or depression varies with the liquids employed.* Water will rise higher than alcohol. The thickness of the tubes makes no difference, nor does their character, whether glass or metal.

4. *Ascension and depression are diminished by increasing temperature.* Heat diminishes both cohesion and adhesion, the former a little the more.

What are some illustrations of capillarity?

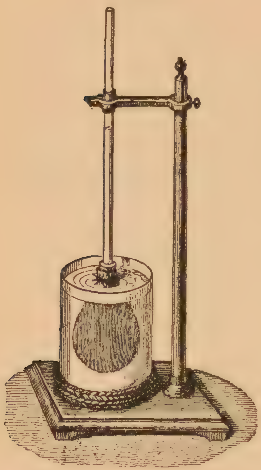
This action is seen when oil rises in a lampwick or ink in blotting paper, or when water enters dry wood with force enough to split rocks. Sap rises in plants with great force, due to capillarity.

What is osmose?

When we separate two liquids or two gases by a thin porous partition, organic or inorganic, we find a current sets in from one to the other. This diffusion is called *osmose*, impulse, or *diosmose*, an impulse through. Take a glass tube and bind to one end a membranous bag filled with syrup or blue-vitriol solution. Immerse it in

a jar of water (Fig. 19), and in a short time it will be found that liquid has risen in the tube, and the water is seen to be tinged with the blue solution.

FIG. 19.



There are two opposing currents, and the one *toward that liquid which increases* is called *endosmose.* The increased liquid is generally the denser one. The other current is *exosmose*, or outward impulse.

What are colloids?

It is found that crystallizable substances are best for osmosis; glue-like substances, like gum and gelatin, do not pass readily through septa, and are called *colloids.*

What is dialysis?

This principle of unequal diffusibility is of great importance in laboratories in preparation of drugs and chemicals. The process of separating colloids from crystalloids is called *dialysis.*

The *dialyzer* is a glass vessel with a parchment bottom. If the liquid contents of a stomach suspected of containing poison be placed in it, and the vessel be floated in water, arsenic or strychnine, if present, would pass through into the water, leaving the albuminous matter of food behind.

One of the necessary conditions for osmosis is that the liquids be capable of mixing; there is none between water and oil.

What is diffusion and effusion of gases?

All these phenomena are seen to a high degree in gases. When two are separated by a porous partition, an exchange takes place, and does not cease until the composition of the gas on both sides is the same. This is *diffusion*, and its rapidity depends on Graham's law, p. 57.

Effusion refers to the passage of a gas into a vacuum through a minute aperture .013 mm. in diameter. The law for effusion is the same as for diffusion.

CHAPTER VI.

GASES.—ATMOSPHERE.—BAROMETERS.—PUMPS.

What are fluids and some of their common properties?

Gases and liquids are called *fluids*, and, from their properties, especially those of a gas, are elastic fluids. The lightest liquid is many times heavier than the heaviest gas. Water is 770 to 800 times heavier than air.

A gas is a body whose molecules are in a constant state of repulsion; in a liquid the repulsion is slight, and more than counterbalanced by cohesion. The two have some common properties—viz.:

(1) Mobility, are not viscous.
(2) Compressibility, hence elasticity or tension.
(3) Weight.

Solids, liquids, and gases possess these three, only differing in degree.

(1) This is self-evident from our supposition as to the constitution of matter.

What is Boyle's law?

(2) In 1662 the law of compressibility of gases was discovered by Boyle, and also independently by Mariotte in 1679:

The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure which it bears.

This law can be demonstrated by means of a U-shaped tube, with the short arm closed. Pour in Hg till the surfaces in the two arms are on the same level. The tension of air in the short arm must be one atmosphere, as it exactly balances the outside column of air. Pour in more Hg until the short closed arm is half full, and it will be found that the height of the long column of Hg is equal to that of the barometer at the time of the experiment. That is, the column of air in the short arm is compressed by the original one atmosphere plus the long column of Hg, which is another atmosphere. The volume of air in the short arm has been reduced to one half by a pressure of 2. We can also prove the converse, and

see that if the pressure be reduced one half, the volume is doubled. This law does not quite hold good for high pressures.

Manometers are instruments used to measure the amount of pressure or tension exerted by liquids or gases.

Closely allied to compressibility is elasticity, or the power to recover former volume after pressure is removed. All fluids are perfectly elastic. Liquids are, but, as they are practically incompressible, we need not consider their elasticity.

Pressure or cold will convert every gas into a liquid. O, H, N, CO_2, and marsh gas (CH_4) had not been liquefied till eight or ten years ago. They have been since, and all liquids have been solidified.

Describe the third property, weight.

(3) The air-pump is necessary for weighing gases or air. An hermetically sealed globe is weighed when empty (exhausted by an air-pump) and when full of the given gas. The noted difference is the weight required.

At 60° F., and with the barometer at 30 in.,

100 cu. in. of air weigh 30.93 gr.
1 cu. ft. of air weighs 534.470 gr.
1000 cu. ft. of air weigh 76.352 lb. av.

Every gas is affected by gravity, even H, which is the lightest of all, and consequently every gas exerts pressure. 100 cu. in. of H weigh 2.14 gr.

What is atmospheric pressure?

We live at the bottom of an ocean of air, which is held to earth by gravity and partakes of the earth's rotation. This layer of air may extend upward 50 to 200 miles. Some think it has no limit, but as the air expands its expansive force decreases, and at a certain height there is probably an equilibrium established between the repulsion of the molecules and the action of gravity.

If this ocean were of uniform density, its whole thickness would be only about five miles, and some peaks of the Himalayas would rise above it. The weight of the atmosphere generally means that of the whole air above us, and not the weight of a definite volume. It exerts pressure in all directions—downward, as may be seen by the bursting membrane from beneath which air has been extracted

(Fig. 20). It exerts upward pressure, as seen by the *weight-lifter*, where air in a cylinder is removed from above a piston to which

FIG. 20.

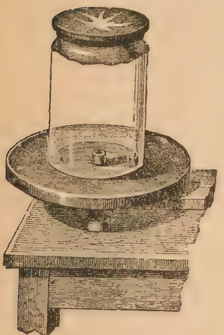


FIG. 21.

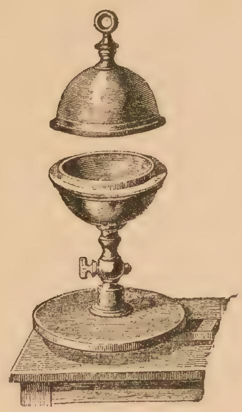
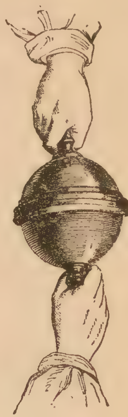


FIG. 22.



weights are attached. It exerts pressure in every direction, as proven by the *Magdeburg hemispheres* (Figs. 21 and 22). When the air is removed from their interior they cannot be separated without a powerful effort, no matter in which position they are held. This is known as Von Guericke's experiment.

What is meant by one atmosphere?

From experiments to follow it will be proven that this air-pressure is about 15 lb. to the square inch—*i. e.* a column of air 1 inch square from the surface of the earth to the surface of the aërial ocean weighs 15 lb.; it is also about 1 ton to the square foot or 1 kilo to the square centimetre. This weight is what is meant by *one atmosphere.*

An average-sized man sustains an external pressure of about 15 tons.

If the area of the bottom of a tin pail be 1 sq. ft., it sustains a pressure of about 1 ton. How can a person carry such a pail, and why is its bottom not forced out?

What was Torricelli's experiment?

Aristotle and Galileo both failed to weigh air or find it had

weight. Viviani was a pupil of Torricelli, and in 1643 performed the following experiment: he took a glass tube, closed at one end and of a greater length than 30 inches, and filled it with mercury. He then carefully inverted it, with his thumb over the open end of the tube, in a vessel of Hg. He found that in the tube a column of Hg stood about 30 in. high above the level of that in the vessel, and above this column was an unoccupied space. He and his friends had always said that "Nature abhorred a vacuum;" hence their amazement to see that this abhorrence ceased after a certain limit. Torricelli repeated and published the experiment.

What did Pascal prove?

It was Pascal, a Frenchman, who in 1648 really conceived the idea that air held the mercury up in the tube. If so, he argued that the column should not be so high upon a mountain-top, as there is less air to exert pressure. This he investigated, and proved that the column was supported by the weight of the atmosphere. He used other liquids besides mercury.

What are barometers?

Instruments for measuring atmospheric pressure are called *barometers*, weight-measurers; and this simple tube, filled with Hg as used by Torricelli, was the first one ever devised. The space at the top of the tube is called the *Torricellian vacuum.*

It is from weighing this column of Hg that we get the amount of air-pressure as above stated—15 lb. to the square inch. 1 cu. in. of Hg weighs $\frac{1}{2}$ lb.; so if a barometer have a cross-section of 1 sq. in., the column standing 30 in. high will weigh 15 lb.

The more air you have or the heavier it is, the higher will be the column; the less air or the less dense the air, the lower the column.

How high will any fluid rise in the tube?

The height of the fluid depends inversely upon the sp. gr.

At what height would water stand in the tube, its sp. gr. being 1 and that of Hg 13.60?

$$1 : 13.60 :: 30 \text{ in.} : x, \text{ height of water.}$$

$$\begin{array}{r} 30 \\ \hline 408.00 \end{array} \text{ in. or 34 feet. Ans.}$$

Barometers are of several kinds. Ordinarily, the pressure is measured by the height of a column of Hg, as in Torricelli's experiment; other liquids may be used, and one, the aneroid, has no liquid at all.

Describe the cistern barometer?

This variety consists of a straight glass tube about 33 in. long,

FIG. 23.

FIG. 24.

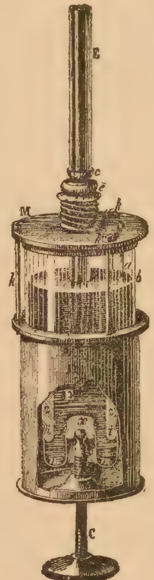


FIG. 25.

closed at one end, filled with Hg, and dipping into an open cistern containing the same metal. (Fig. 23.) There is only one fault with it—that the zero of the scale does not always correspond with the level of the Hg in the cistern.

5

Describe Fortin's barometer.

Fortin's barometer differs from the above in the shape of the cistern. Its base is made of leather, which can be raised or lowered by means of a screw, thus allowing a constant level (Fig. 24).

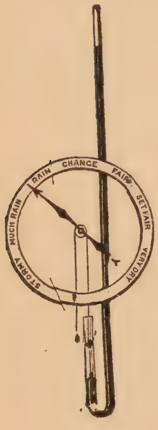
What is the siphon barometer?

Gay-Lussac's siphon barometer is a bent glass tube, one branch of which is much longer than the other. The longer branch is closed at the top and filled with Hg, as in the cistern barometer, while the shorter branch, being open, serves as a cistern (Fig. 25). The difference between the two levels is the height of the barometer.

Describe the wheel barometer.

This one was invented by Hooke: it is a siphon barometer, and especially intended to indicate good or bad weather. In the shorter leg of the siphon there is a float which rises and falls with the Hg. A string attached to this passes over a pulley, and at the other end there is a light weight. A needle fixed to the pulley moves round a graduated circle marked *rain*, *fair*, *dry*, etc. (Fig. 26).

Fig. 26.



Common *weather-glasses* of this kind are of little use, because they are not delicate or precise, and are only suited for the place in which they are manufactured. If made in London, they indicate London weather, and would not be useful in Denver.

What other liquid barometers are there?

A *glycerin* barometer has been constructed, requiring gas tubing $\frac{5}{8}$ in. in diameter and 28 feet long. Small alterations in the atmosphere cause considerable oscillations in the height of the glycerin. To prevent the attraction of moisture, the liquid in the cistern is covered with a layer of paraffin oil.

Water barometers have also been made.

Describe the aneroid barometer.

This instrument takes its name from the fact that no liquid is used

in its construction (ἀ, "without," νηρὸς, "moist"). It consists of a cylindrical metallic box exhausted of air, the top of which is made of thin corrugated metal, so elastic that it readily yields to alterations in atmospheric pressure (Fig. 27).

FIG. 27.

On increase of pressure the top is pressed inward: when pressure is diminished, the elasticity of the lid, aided by a spring, tends to move it in the opposite direction. These motions are transmitted by multiplying levers to an index. These barometers may be made of such delicacy as to show the difference in pressure between the height of a table and the floor.

They are very liable to get out of order, and should be frequently compared for correction with a standard barometer.

What are the advantages of Hg for a barometer?

1. It is the heaviest liquid, and so stands at least height. 2. It does not wet glass; there is no adhesion between them.

The mercury should be pure, however, and free from oxide, and the Torricellian space should be free from air or aqueous vapor.

What corrections are necessary for barometers?

(1) For temperature;
(2) " elevation above sea-level;
(3) " capillarity;
(4) " (*a*) accidental, (*b*) diurnal variations,
(5) " Hg vapor.

(1) Temperature of course causes the Hg to expand or contract in a barometric column, just as it would in a thermometer. So the height observed must be reduced to a determinate temperature, usually that of melting ice.

(2) The use of the barometer in determining elevation will be

spoken of later. Here we mean that the observations made in one place, if used in another of a different level, must be corrected.

(3) In cistern barometers there is always a depression of the column of Hg, due to capillarity, unless the internal diameter of the tube exceeds $\frac{8}{10}$ of an inch. The height of the meniscus (Fig. 18) has to be found, and the resulting correction taken from tables.

(4) Two kinds of variations are observed:

(*a*) *Accidental* variations present no regularity. They depend on seasons, the direction of wind, and geographical position. They are not observed, however, at the equator or in the tropics.

(*b*) *Daily* variations are produced periodically at certain hours of the day, and they occur with such regularity in the tropics that a barometer can almost serve as a clock. There seem to be tides in the atmosphere which rise and fall twice a day. The barometer, due to this cause, is highest at 10 A. M. and 10 P. M., and lowest at 4 A. M. and 4 P. M.; and these hours appear to be the same for all climates, whatever be the latitude. They merely vary a little with the seasons.

What are the uses of the barometer?

(1) Indirectly to determine the state of the weather;
(2) To ascertain heights.

(1) It must be remembered that the barometer only serves to weigh the atmosphere, and that frequently a change of weather coincides with a change of atmospheric pressure, but they are not necessarily connected. In dry weather the atmosphere is dense, and consequently the pressure on the Hg causes it to stand higher than it does in wet weather, when the air is rarer and contains more aqueous vapor. Generally the barometer falls as the thermometer rises.

(It seems that air would be more dense in wet weather, but such is not the case.) Generally speaking, a column above 30 in. or 760 mm. indicates fair weather, and below 30 in. indicates rain. When the column rises or sinks slowly for two or three days toward fair weather or rain, the indications are extremely probable. Sudden variations in either direction indicate bad weather or wind.

(2) To *determine heights*, as of a mountain, simultaneous observations should be made at the foot and at the top. The results in terms of feet or metres may be obtained from certain tables.

At the height of 2.7 miles we have left half the ocean of air behind us—*i. e.* the barometer stands at 15 in.; at 5.4 miles it would stand at 7.5 in.; at 16.23 miles the barometric column is .468 in. high.

Three-fourths of all the atmosphere is within the level of the highest mountains; $\frac{63}{64}$ is within 16 miles of the earth. It is computed that if we could bore a hole 35 miles deep into the earth, the air at the bottom would be 1000 times as dense as at the sea-level, and water would float on it.

What law is true for the mixture of gases?

As has been before stated, all gases mix uniformly, and they mix on the slightest opportunity. The mixture remains homogeneous, unless chemical action or some outside cause intervene. These gaseous mixtures follow Boyle's law, as has been proved for air, which is a mixture of N and O.

How do liquids absorb gases?

Water and many liquids possess the property of absorbing gases, but the same liquid does not absorb equal quantities of different gases. Bunsen has devised three general laws for gas absorption by liquids:

1. *The weight of gas absorbed is proportional to the pressure.*
2. *The quantity of gas absorbed decreases with the temperature.*
3. *The quantity of gas absorbed is independent of the nature and of the quantity of other gases which may be already held in solution.*

Water may absorb its own volume of CO_2 and 430 times its volume of ammoniacal gas.

CO_2 driven into water under pressure gives us *soda-water*. There is no soda, however, and the CO_2 is liberated on removal of pressure.

How do solids absorb gases?

The surfaces of all solid bodies attract molecules of gas and become covered with a layer of *condensed* gas. Porous substances have a greatly increased surface, and so have great absorptive power. The absorption by metals appears to be of the nature of true solution; chemical reactions also may occur. Charcoal from box-wood

and cocoanut is highly absorbent; cocoanut charcoal takes up 171 volumes of ammonia and 73 of CO_2 at ordinary pressure. Gases are also said to be *occluded* when absorbed on the surface or in the mass of a metal. Solid platinum absorbs four times its volume of H. Palladium absorbs, even when cold, 980 vols. of H. It probably forms an alloy with palladium like true metal, and must be in a liquid or even solid state when thus absorbed and condensed.

Does Archimedes' principle apply to gases?

It does, and bodies in a gas or in air lose a part of their weight equal to that of the air which they displace, and all that has been said of liquids in this regard is true of gases. This is demonstrated by means of the *baroscope.*

A scale-beam supporting at one end a leaden weight and at the other a hollow sphere is exactly horizontal in air. It is put beneath the receiver of an air-pump, and when a vacuum is produced the sphere sinks. Before the air is exhausted each body is buoyed up by the weight of the air which it displaces. As the sphere is much the larger body, it is buoyed up by a larger amount of air, and thus, though in reality the heavier body, it is balanced in air by a small leaden weight.

Why do balloons rise?

Balloons are hollow spheres made of light impermeable material and filled with hot air, H, or coal-gas. The latter is generally used, and this balloon must be twice the size of one for H gas. They rise because their weight is less than the weight of the air which they displace—*i. e.* something heavier is pushing them up. Balloons were invented by the brothers Montgolfier, and their first ascent was successfully made in June, 1783.

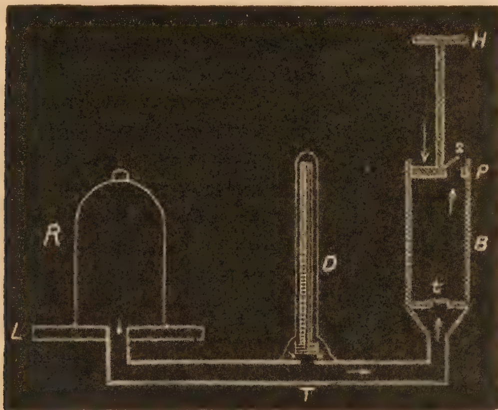
Great possibilities of scientific interest, of war observations, or of future modes of locomotion lie in Archimedes' principle thus applied.

Describe an air-pump.

These are instruments by which air can be greatly rarefied in a given space. An absolute vacuum cannot be produced by them. They were invented by Von Guericke in 1650, soon after Torricelli's experiments with the barometer.

The principle depends upon the elastic force of air. If we take away a portion from the receiver *R*, the remainder fills up the whole space until it finally becomes so rarefied that its tension can no longer lift the valve at *t*. (Fig. 28.) *R* is the glass receiver to be ex-

FIG. 28.



hausted. *B* is a hollow cylinder of brass containing the close-fitting piston *P*. If the piston be descending, compression of air in *B* closes the valve *t* and opens the valve *s*, and the enclosed air escapes. When the piston ascends valve *s* closes, and what would otherwise be a vacuum above *t* is filled by the expanding air from *R*, and valve *t* is opened.

The air-pump gauge is at *D*, under a bell glass, and consists of a simple barometer or U-shaped tube, with one end open. As the air-pressure is removed the Hg column sinks. It is a very good pump that reduces this column to 3 mm. The above diagram only illustrates the simplest form of air-pump. Very elaborate ones are constructed with double pistons, special stopcocks, etc.

What is Sprengel's air-pump?

This is a most efficient pump, depending on the principle of converting the space to be exhausted into a Torricellian vacuum. Mercury is allowed to fall in a tube *c d*, its flow regulated at *c* by a clamp (Fig. 29). It falls past the aperture of the vessel, *R*, to be exhausted,

and the bubbles of air are entangled as it were by the falling Hg, until finally we have a barometric tube whose Torricellian vacuum is the receiver R. By this means the air in R is reduced to less than one-millionth its usual density. The exhaustion may be carried much farther by mechanical or chemical means, as by heating charcoal in the receiver while a vacuum is being formed, and then allowing it to cool. It then absorbs most of the rarefied air that remains. Or oxygen may be the gas in the receiver, and the exhaustion carried as far as possible, when copper previously placed there is heated to redness. Oxide of copper is formed and the vacuum is nearly complete.

FIG. 29.

Water may be used instead of Hg, constituting *Bunsen's Sprengel pump.*

What are the uses of air-pumps?

Sprengel's pump is used for producing vacua for the incandescent electric lights. It is by this principle also that the traps in water-pipes are siphoned, the contents of the soil-pipe falling from an upper story. This would allow the free passage of sewer-gas, etc. into the house, and is remedied by *back-airing* the traps—*i. e.* by having a fresh-air pipe connected between the trap and soil-pipe. Then the Sprengel pump action is effective only in drawing in air from above the roof, and not in emptying the traps.

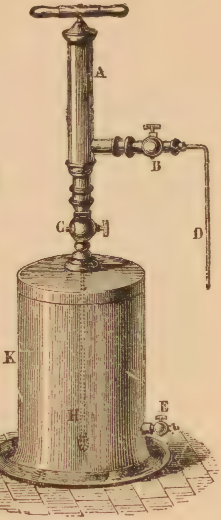
The air-pump is also used for many experimental purposes, showing the properties of the atmosphere, that by reason of the O it contains it supports combustion and life—that substances in vacuo are not liable to ferment.

Lessened air-pressure has effect on the boiling-point. Melting-

points do not vary. The principle is made use of in sugar-refineries and condensed-milk establishments.

Fig. 30 *a*.

Fig. 30.



Describe the condensing pump.

The condensing pump is just the opposite of the air-pump, and the position of the valves is reversed. The lateral valve *o* (Fig. 30 *a*) will swing in a direction opposite to *s* of Fig. 28. Let K be the receiver of the condensed gas, A the cylinder containing a solid piston. D connects with the gas or air to be condensed (Fig. 30). When the piston descends the valve *o* closes, and the elastic force of the compressed air opens the valve *s*. The reverse takes place when the piston ascends.

What are the uses of the condenser?

It is chiefly used for charging liquids with gases. The tube D is connected with a reservoir of gas. The pump exhausts this gas, and forces it into K, which contains the liquid. Artificial gaseous and effervescing waters are thus made.

The principle is also used by plumbers in testing gas-pipes; it is used in ventilating mines. in supplying air to blast-furnaces, to air-brakes, and drilling-machines.

What are pneumatic tubes?

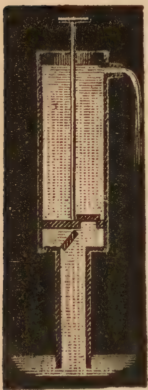
The Western Union Telegraph Company in New York employs *pneumatic tubes* in sending messages to its central office from various stations in the city. Tubes of uniform size and free from abrupt curves are laid under ground, and the roll of paper or letter is placed in a cylindrical box which fits the tube. At the receiving end a steam air-pump exhausts the air in front of the box, and a steam condensing pump also pushes it from the sending station.

Such tubes are proposed for the Post-Office Department, whereby the mail can be rapidly distributed from the central office to the substations. The *pneumatic post* is used in London.

What are pumps?

Pumps are machines which raise fluids by suction, by pressure, or by both efforts combined. The arrangement of valves in the *lifting* or *suction* pump (Fig. 31) is the same as for the air-pump. When the piston rises a tendency to a vacuum is produced beneath it, and the outside air forces the fluid up through the lower valve. The weight of the water above the piston closes the upper valve, and the water is discharged from the spout. Liquids are sometimes said to be raised by force of *suction*. There is no such force. What is meant is that atmospheric pressure forces the liquid to occupy the vacuum produced by a retreating piston or by lips applied to an aperture.

FIG. 31.

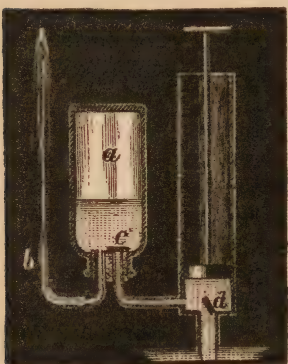


From how deep a well, therefore, could you draw water, or how high can the bottom of the barrel be above the surface of the liquid? Evidently only so high as the atmosphere will force this liquid, inversely as its sp. gr. It is 34 feet for water (practically only 26 or 28 ft. with the usual pump) or 30 in. for Hg.

Describe the force-pump.

As usually constructed, it combines both principles of suction and of pressure, and its valves are the reverse of those in the condensing pump.

FIG. 32.



The piston is solid (see Fig. 32). A branch pipe leads to an air-chamber, *a*, which is provided with a valve *c* opening upward. On raising the piston, valve *d* opens, and water is prevented from returning from *a* by valve *c*. When the piston descends the valves reverse their action, and water is forced into air-chamber *a*, condensing the air. The elasticity of this con-

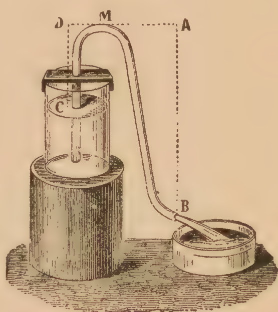
densed air forces the water out at *b* in a continuous stream; otherwise it would escape in jets at each descent of the piston.

The *fire-engine* is a force-pump in which a steady stream is maintained by means of an air-chamber.

Describe the siphon.

The siphon is an instrument used for transferring a liquid from one vessel to another through the agency of atmospheric pressure. It consists of a bent tube open at both ends and with unequal legs. Let the tube be filled with some liquid, and the two ends closed, and let the shorter leg dip in the liquid, as seen in Fig. 33. Or, the shorter leg having been placed in the liquid, the mouth may be applied at B. It will continue to run as long as the short leg dips in the liquid or until the level of the receiving vessel equals that of the other. It would not run if the height C D were greater than that of a column of liquid which can be balanced by atmospheric pressure. The reason of the flow is this: At the two points C and B there is an upward pressure in each case of one atmosphere. The downward pressure at C is that of the column of water C D acting by gravity. The downward pressure at B is the weight of the column A B, but this latter is the greater. The excess of downward pressure is at B, and the excess of upward pressure is at C. Suppose C D weighs 1 lb. and A B 2 lbs.; then the upward pressure at C is $15 - 1 = 14$ lbs.; upward pressure at B is $15 - 2 = 13$ lbs. The 14 lbs. push at C more than counterbalances the 13 lbs.; hence the flow toward B.

FIG. 33.



Could a siphon act in vacuo?

What are the uses of the siphon?

A heavy liquid may be removed from beneath a light one, or a liquid may be removed in a clear state without disturbing sediment.

Gases heavier than air may be siphoned like liquids. Gases lighter than air may be siphoned by inverting both the vessels and the siphon. Hg may be siphoned by a solid bar of lead.

Describe the intermittent siphon.

An intermittent siphon is arranged in a vessel which is fed by a constant stream through a tube smaller than the siphon tube. A cup containing a nearly circular siphon of this kind is called the *Tantalus cup*. The level of the liquid gradually rises in the vessel and in the convexity of the siphon, which it finally fills, and the water begins to flow out. The fluid level soon sinks below the end of the short arm, and the siphon is empty and the flow ceases. But as the vessel is continually supplied, the level again rises and the flow is reproduced.

This principle explains many natural intermittent springs, the flow ceasing and recommencing several times an hour or once in several days or months.

BOOK II.

ON HEAT.

CHAPTER VII.

THERMOMETERS.—FIRST EFFECT OF HEAT.

Define heat.

The term "heat" is used in two senses: it is a sensation or it is the objective cause of the sensation. In the latter sense it is the *energy of molecular motion;* this energy is kinetic, not potential. Heat can only be measured during its transference or transformation.

What are the two theories as to the cause of heat?

(1) Emission theory—mechanical.
(2) Undulatory theory—dynamical.

(1) This was the old view, and regarded heat as an imponderable substance called *caloric*, and the entrance of this substance into bodies caused heat, and its egress cold.

(2) The *undulatory theory* is better, and generally adopted, and it brings heat into line with light and sound. By it heat is considered to be molecular motion, and it is transmitted to other bodies or molecules by undulations set up in an imponderable ether which fills all space, even molecular spaces. This is also called luminiferous ether, as it carries light.

Sound is propagated by waves of air.

When a hammer descends on an anvil, its motion ceases, and the only observable effect is heat; the vibratory motion of the molecules in the hammer and in the anvil is increased. A body is heated by having the motion of its molecules quickened, and cooled by parting

with some of its molecular motion. A point may finally be reached where the kinetic energy is zero and the molecules are at rest. This point is the *absolute zero of temperature* (p. 91).

We shall see later how heat and mechanical energy are related, so that a definite quantity of one always produces a definite quantity of the other.

Define temperature.

Temperature, or hotness of a body, is the extent to which it imparts sensible heat to other bodies or receives sensible heat from other bodies.

The direction of the flow of heat determines which of the two bodies has the higher temperature. *Temperature* must also be distinguished from *quantity of heat.*

If from a gallon of hot water we dip a cupful, the cup of water is just as hot—*i. e.* has just the same temperature—as that of the larger vessel; but of course there is a great difference in the quantities of heat which the two bodies of water contain.

What are the general effects of heat?

They are classed under three heads:

(1) Rise of temperature;

(2) Internal work $\begin{cases} \text{changes volume;} \\ \text{changes state;} \end{cases}$

(3) External work, overcomes atmospheric pressure in expanding.

As a result of (1) and (2) heat also

(4) Produces electricity;
(5) Produces light.

(1) Raises temperature. How is it measured? Heat causes all bodies to expand—gases a great deal, liquids less, and solids still less. Owing to the imperfection of our senses, we are unable to measure heat and cold by the sensations they produce in us; hence we have to depend upon the observed expansion of bodies in one or other of their three states.

What are thermometers?

Thermometers are instruments for measuring temperature. They do not record the amount of heat, only its degree.

Air thermometers are most accurate and best for a standard.

Pyrometers (fire-measurers), based upon the expansion of solids, are pretty accurate, but liquid thermometers are most practical and useful, solids expanding too little, and gases too much.

What two liquids are used?

Mercury and alcohol are the only liquids used—Hg because it boils only at a very high temperature, and alcohol because it does not solidify at very low temperatures.

What are the advantages of Hg?

1. It does not boil readily;
2. Does not freeze readily;
3. Has low specific heat;
4. Has practically uniform expansion between —36° C. and +100° C.;
5. Is opaque;
6. Does not adhere to glass;
7. Is easily obtained pure;
8. Is cheap.

What are the disadvantages of Hg?

1. It expands irregularly below —36° C. and above 100° C.;
2. Solidifies at —40° C. and —40° F.;
3. Boils at 350° C. (662° F.).

Describe a mercurial thermometer.

A mercurial thermometer consists of a capillary glass tube, at one end of which is blown a bulb. Both bulb and a part of the stem are filled with Hg, and its expansion is measured by either a scale on the stem itself or one on a frame behind it. The space above the mercury is a partial vacuum, containing the vapor of Hg.

What are the steps in the construction of a thermometer?

(1) Calibrating the tube; adding suitable sized bulb.
(2) Filling the thermometer;
(3) "Curing" the thermometer;
(4) Graduation of thermometer and determination of the fixed points.

(1) As the tubes are drawn out by the glassblower and cut up

into lengths, it is easy to see that the calibre of the tube in one part may differ from that of another. Uniformity of calibre is detected by introducing a bead of Hg, which may be about 1 in. long, in the capillary tube, and noting if this thread occupies the same length in different parts, temperature remaining the same. This will show equal or unequal capacities. In the latter case the tube is rejected. Practically, the tubes are never absolutely uniform.

(2) *Filling the Thermometer.*—After a bulb is blown at the bottom of the tube, a small funnel is blown at the top and partly filled with Hg. The air in the bulb is expanded by heat, and some of it escapes by the funnel. On cooling the remaining air contracts, and a portion of Hg falls into the bulb. This is repeated until the bulb and part of the tube are full of Hg. The Hg is then heated to boiling, and the tube, being full of expanded Hg and Hg vapor, is hermetically sealed.

(3) "*Curing.*"—By this term is meant that a thermometer is laid aside for a year or two after filling and before graduating, so that the overstrained glass may assume a permanent shape. It will change its molecular condition, and it is allowed to "season."

(4) *Graduation.*—The thermometer being filled and seasoned, it must be provided with a scale to which variations of temperature can be referred. First of all, two points must be fixed which represent identical temperatures, and which can always be readily reproduced. Fortunately, Nature provides us these two standards. Ice is found to melt always at the same temperature. The melting-point of ice and the freezing-point of water are identical. Again, distilled water under certain precautions always boils at the same temperature.

How are the fixed points determined?

To fix these points on the stem of the thermometer the bulb and part of the stem are placed in melting snow or pounded ice for about fifteen minutes, and a mark made at the level of the Hg. This is the *freezing-point.* Bunsen says it should be placed in freezing water instead of melting ice.

The second point is fixed by suspending the instrument in steam rising from boiling water. The nature of the vessel and the salts dissolved influence the temperature of boiling water, but not that

of the vapor produced; *i. e.* the temperature of steam never varies provided the pressure is 760 mm. (For every 27 mm. difference in the height of the barometer there is a difference in the boiling-point of 1° C.) The bulb must not dip in the liquid, even with distilled water.

This level of Hg is marked on the tube and called the *boiling-point.* Now, the space between these two points is always a definite quantity, and is taken as the unit of temperature, just as a foot or metre is taken as the unit of length; but the foot-rule is conveniently divided up into inches for the purpose of having smaller units; so likewise the unit of temperature is divided into a number of parts of equal capacity called *degrees*, and the scale may be extended above or below the fixed points.

What are the three scales?

Depending upon the way in which the space between the fixed points may be divided, we have three different-sized degrees.

Should one man divide the space into 180 equal parts, another into 100, and another into 80, evidently the first one would get quite small degrees, there being so many of them; the next would be larger; and the last largest of all. Fahrenheit divided the space into 180°, and his scale is used in England and the United States—abbreviated F.

	F.	C.	R.
Water boils.	212	100	80
	180 (9)	100 (5)	80 (4)
Ice melts or water freezes.	32	0	0
	0		

The Centigrade scale (100 steps), invented by Celsius, has 100°, and is coming into universal use—abbreviated C.

The Réaumur scale has 80°, and is used more or less in Germany—abbreviated R.

It will be noticed that Fahrenheit's 0 point does not correspond with the others, while his highest point does. The way this hap-

pened was this: he took as his lowest point the temperature obtained by mixing equal weights of sal ammoniac and snow. This was the lowest temperature then (1714) known, and was thought to represent absolute cold. His boiling-point is that of water, and the reason that he divided the space into 212 divisions is that he was experimenting with 11,124 volumes of Hg. On heating to boiling-point of water it became 11,336 volumes, or 212 volumes increase; so he took that number of divisions for his scale. When Fahrenheit's thermometer is placed in melting ice, it stands at 32°, and not at 0°. Note that the degrees above 0 point are written as +, below as —.

How do you convert degrees of one scale into those of another?

If we are converting F. degrees, we must first subtract 32, in order that the degrees may count from the same part of the scale; then,

$$
\begin{aligned}
180^\circ\text{ F.} &= 100^\circ\text{ C.} = 80^\circ\text{ R., or}\\
9^\circ\text{ F.} &= 5^\circ\text{ C.} = 4^\circ\text{ R.}\\
1^\circ\text{ F.} &= \tfrac{5}{9}^\circ\text{ C.} = \tfrac{4}{9}^\circ\text{ R.}
\end{aligned}
$$

Reduce 122° F. to C. degrees, thus: The 122° F. mean 122° above his zero, and not above freezing-point; it would be only 90° above that point, first subtracting 32, to get it on the same basis that the C. scale is. 1° F. $= \frac{5}{9}^\circ$ C.; hence 90° equals $90 \times \frac{5}{9} = 50^\circ$ C. 122° F. $= 50^\circ$ C. Ans.

Rules committed to memory are dangerous, and it is better to reason out the result as above, or else use Simple Proportion: 180° F. : 100° C. : : (122° F. — 32) : x° C. Expressed in formula, however, we have (F. — 32) $\frac{5}{9} =$ C.

The main point of difficulty may be the subtraction of 32, or its addition to a negative degree. Remember to do it algebraically. If your algebraical knowledge is not recent, make a diagram of the F. scale and mark the problem upon it.

Convert 6° F. to C.°: 32° subtracted from +6°, or you may say 32° colder than 6° above 0, gives 26° below 0, or —26°. $+6 - 32 =$

$-26 \times \frac{5}{9} = \frac{-130}{9} = -14.4^\circ$ C. 6° F. $= -14.4^\circ$ C. Ans.

212

32

+6

0

—26

Convert —10° F. to C°. :

Consider that if the thermometer now stood at 10° below 0, where it would stand if the weather became 32° colder; evidently at 42° below. $(-10° \text{ F.} - 32°) = -42 \times \frac{5}{9} = \frac{-210}{9} = -23.3° \text{ C.}$ Ans.

Convert 0° F. to C.°:

$$0° \text{ F.} -32° = -32 \times \tfrac{5}{9} = \frac{-160}{9} = -17.7° \text{ C.}$$

To convert C.° to those on a F. scale.

Convert 50° C. to F.°:

We know that 100° C. = 180° F.

$$5° \text{ C.} = 9° \text{ F.}$$
$$1° \text{ C.} = \tfrac{9}{5}° \text{ F.}$$

If 1° C. = $\frac{9}{5}$° F., 50° C. will be 50 times as much. $50° \text{ C.} \times \frac{9}{5} = 90° \text{ F.}$ As the 50° C. were reckoned above freezing-point, the 90° F. mean 90 degrees above the same point on the F. scale. But all scales begin to reckon from the 0 point, which with Fahrenheit is 32 degrees lower than the others. So 90° above freezing is 122° above zero. 50° C. = 122° F. Formula is $\text{C.}\frac{9}{5} + 32 = \text{F.}$

Convert —10° C. to F.°:

$-10 \times \frac{9}{5} = \frac{-90}{5} = -18.$ Here the minus sign means 18° below the horizontal line of our diagram—*i. e.* below freezing-point. See where this would be on the F. scale above or below 0, for it must be referred to that. It is the same as 14° above 0, or —18° F. + 32° F. = +14° F. —10° C. = +14° F.

Convert —40° C. to F.°:

$-40 \times \frac{9}{5} = -72.$ That is 72° below freezing, or 40° below 0. —72° F. + 32° F. = —40° F. Ans. Notice that the two scales here meet.

Convert 0° C. to F.°:

$0 \times \frac{9}{5} = 0 + 32 = 32°$ F. Ans.

Réaumur can be converted into F.° or C.°, or F.° and C.° can be converted into R.°, by similar methods. $\text{R.}\frac{9}{4} + 32 = \text{F.}°$

The following problems are suggested for solution:

Convert to C.°:

+6° F.	+86° F.
+40° F.	+20° F.
+300° F.	—8° F.
+33° F.	0° F.
+80° F.	+32° F.
—10° F.	+212° F.

Assume these same figures to be on the C. scale, and convert them to F.°.

What are the causes of inaccuracy in thermometers?

Thermometers are never accurate. The glass contracts and expands, as well as the Hg. Causes of inaccuracy are—

1. Imperfect calibration;
2. Moisture in the Hg before tube was sealed;
3. Lack of thorough curing;
4. Incorrect graduation;
5. Displacement of zero.

Explain the fifth cause.

The displacement of zero may amount to as much as 2°, and it generally rises, so that when the thermometer is placed in melting ice it no longer sinks to 0°. It is attributed to a diminution in volume of bulb and stem, due to the pressure of the atmosphere.

Besides this slow displacement, there are often variations in the position of 0 when the thermometer has been exposed to high temperatures, caused by the fact that the glass does not contract to its original volume on cooling.

Describe the alcohol thermometer.

For temperatures below —36° C. alcohol thermometers must be used, for Hg expands irregularly below this, and solidifies at —40° C.

The alcohol is colored, and in the graduation this thermometer is placed in the same bath with a standard mercurial thermometer, so the two indicate the same temperature under the same conditions.

What are the advantages and disadvantages of alcohol thermometers?

Advantages: 1. The alcohol is a liquid;
2. It does not solidify till —130° C. is reached.

Disadvantages: 1. It boils at 78° C.:
2. It expands very irregularly as it approaches this point.

There is also a *weight thermometer*, where the temperature is calculated from the Hg which overflows.

Describe the air thermometer.

These thermometers are based on the expansion of air by increase of temperature. A bulb is blown on the lower end of an open capillary tube. The bulb is filled with air, and its expansion is denoted by the rise and fall of colored H_2SO_4 in the tube. The scale is made by comparing it with the indications of a Hg thermometer. At each observation a correction has to be made for atmospheric pressure. Such instruments are very sensitive, and are useful in some scientific investigations.

What is a delicate and an accurate thermometer?

A thermometer may be *delicate* by indicating very small differences of T.; it usually has a large bulb and small tube with wide degrees, so differences can be easily seen.

A thermometer is *sensitive* when it indicates changes quickly; it depends upon the surface area of the bulb.

A delicate thermometer is not necessarily *accurate*. An *accurate* thermometer shows changes in T. correctly.

What are clinical thermometers?

These have a small, thin bulb, so as to quickly indicate changes of T. They range from 90° F. to 110° or 112° F. The average T. of health is 98.6° F. or 37° C. These are registering thermometers, and generally have an index of a detached portion of the column of Hg.

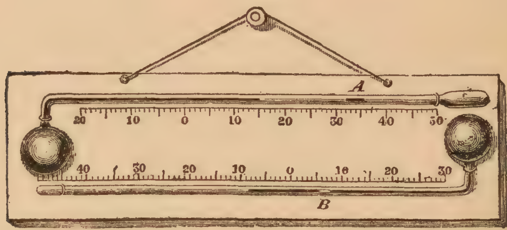
Describe the maximum and minimum thermometers.

Recording thermometers are used mostly for meteorological purposes, and are constructed to indicate maximum and minimum points, thus avoiding continuous observation.

Rutherford's is the simplest. On a rectangular piece of plate glass (Fig. 34) two thermometers are fixed with stems horizontal. *A* is the maximum thermometer, and contains Hg. *B* is the mini-

mum, and contains alcohol. In *A* the index is a small piece of iron wire moving freely. As soon as the Hg contracts, the wire remains at the point where it had been pushed, for there is no adhesion between iron and Hg. The wire can be moved back by a magnet. In

FIG. 34.



B a small hollow glass tube or an ivory slip is the index. When the column of alcohol contracts, this index goes with it by adhesion. When the column expands, it passes between the sides of the index or through it, and does not displace it.

What is the principle of Dr. Draper's thermometer?

This depends upon the principle that when you heat a piece of metal, the side that expands becomes convex, and hence the ends of the metal turn *from* the expanded side.

What are pyrometers?

Pyrometers are instruments for measuring T. so high that Hg thermometers could not be used. They were devised by Wedgewood, who noticed that earthenware contracted by great heat. The instruments now used depend upon the expansion of gases or upon the electrical properties of bodies. The different kinds are—

1. Bricks which contract at high T.;
2. Metals which expand at high T.;
3. Gases which expand at high T.;
4. Thermo-electric piles;
5. Metals which fuse at known T.

CHAPTER VIII.

SECOND EFFECT OF HEAT.—CHANGE OF VOLUME.

Expansion of Solids.

What dimensions are increased by expansion?

We may consider this expansion in one dimension, or *linear expansion;* in two dimensions, or *superficial;* in three dimensions, or *expansion of volume. Isotropic* bodies have identical properties in all directions. Crystalline bodies are *non-isotropic* and expand differently along different axes. Iceland spar expands along its principal axis, but contracts in other directions.

Linear expansion can be shown by a pyrometer, where a metal rod, with one end fixed, is heated, and the free end moves an index. The cubical expansion of solids can be shown by *Gravesande's ring*, which consists of a brass ball passing freely through a ring at ordinary T. When the ball is heated it expands, and no longer slips through.

What is the coefficient of expansion?

It is the expansion due to the rise of T. of one degree, usually taken from 0° C. to 1° C. The number representing it is a fraction of the size of the body at freezing-point. There are coefficients for linear, superficial, and cubical expansion, the later being three times that of the linear.

In solids the coefficient is peculiar to each body. From 0° C. to 100° C. glass expands $\frac{1}{1160}$ of its volume; iron, $\frac{1}{819}$; copper, $\frac{1}{584}$; silver, $\frac{1}{524}$. The coefficients increase with temperature, and are not quite regular—*i. e.* a body may increase more in size in being heated from 49° to 50° than it did in passing from 0° to 1°. This is true of solids and liquids only. We must have uniformity of expansion in order to have a fixed coefficient.

What are some illustrations of expansion?

Some metals expand about seven times as much as others, and all with almost irresistible force. A wrought-iron rod with a cross-section of 1 sq. in. and 10 in. long, in being heated through 45° C.

would exert a strain of 50 tons. A mile of railroad rails will expand $3\frac{1}{4}$ feet in passing from winter to summer temperature.

This fact of expansion has to be considered in the construction of all large buildings and bridges. The Goddess of Liberty moves by expansion when the sun is on it. A curious case of incorrect surveys occurred at Washington, D. C., by taking the head of the goddess on the Capitol as a fixed point. Illustrations are numerous.

Railroad rails must have a small space left between them. Water-pipes are fitted with telescopic joints. If glass is heated or cooled rapidly, it cracks, for it is a poor conductor and becomes unequally affected. The same is true of a crystal of S.

What are some of the applications of the principle?

The contractile force after expansion is seen in setting hot tires on wheels or in riveting boiler-plates with hot rivets; it was also seen in the case of an art-gallery in Paris, the walls of which had begun to bulge. Iron bars were passed across the building and screwed into plates placed on the outside. Each alternate bar was heated by lamps, and when expanded was screwed up. On cooling they contracted and drew the walls together. The same operation was then performed on the other bars.

How is expansion corrected in case of pendulums?

It is necessary that pendulums should remain of the same length at all times, or they will vary in rapidity of oscillations. The pendulum does not make the clock go; it regulates it.

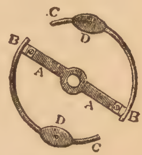
The *compensation pendulum* or *gridiron* pendulum is so constructed that its length will remain constant through changes of T. It is made of alternating bars of steel and brass, so arranged that the expansion of one set counteracts that of the other. There are five steel rods and four brass ones. From the arrangement of cross-pieces above and below, the elongation of the steel rods can only take place in a downward direction, and that of the brass rods in an upward direction, and by as much as one set tends to lower the ball, the other set tends to raise it.

Compensating strips made of copper and iron soldered together, and placed upon a pendulum rod at right angles to it, also make corrections for T. The strip becomes convex or concave, and raises or lowers the ball.

The simplest method is the *mercury* pendulum, invented by an English watchmaker, Graham. The ball consists of a cylinder filled with Hg. When the T. rises, the rod lengthens and lowers the centre of gravity, but at the same time the Hg expands in the cylinder and produces an equal inverse effect. Hg expands about 1 part in 60 in passing from 0° C. to 100° C.

The same principle is applied to the *compensating balances* of chronometers and watches. What we call the watch regulator or *balance-wheel* is furnished with a spiral spring, and the time of the watch depends upon the force of the spring, the mass of the balance, and on its circumference. The wheel is made of compensating strips, the more expansible metal being placed outside, and at the ends of these are small masses of metal (Fig. 35). When the T. rises, the circumference increases and the watch goes slower. A part of the mass must be brought nearer to the axis, which is effected by the incurving of the strips.

FIG. 35.



Expansion of Liquids.

Explain apparent and real expansion.

If we take a thin glass flask provided with a narrow stem, and fill the flask and part of the stem with colored liquid, and plunge it into hot water, at first the liquid in the stem will sink, and immediately thereafter it rises.

The sinking of the column is due to the expansion of the glass, which becomes heated before the heat can reach the liquid; but the expansion of the liquid soon exceeds that of the glass, and its column rises.

Hence in case of liquids we have *apparent* and *real* expansion. The apparent is that which we can actually see. The real or absolute is that which would be observed if the vessel did not expand. Note real and apparent volume, p. 25.

What is the coefficient of expansion of a liquid?

It is the increase of the unit of volume for a single degree. Cubical expansion is alone considered. We may have a coefficient of absolute expansion, and one of apparent expansion.

The absolute expansion of Hg can be obtained by using a U-tube. Heat one arm and surround the other with melting ice. Divide the total expansion—*i. e.* the difference between the heights of the columns—by the temperature-change of the heated arm, and we have the expansion for 1°. Divide this quotient by the height of the column at 0°, and this by definition is the real coefficient, viz. $\frac{1}{5550}$ between 0° and 100°.

All liquids have different coefficients, and hardly any expand uniformly, this irregularity increasing as the liquid nears its boiling- or freezing-point.

Olive oil expands	$\frac{1}{12}$	from 0°	to 100° C.	
Water	"	$\frac{1}{20}$	"	"
HCl	"	$\frac{1}{27}$	"	"

The force which liquids exert in expanding is very great, and equal to that which would be required to bring them back to their original volume. It would require 9000 lb. to prevent Hg from expanding while being heated from 0° C. to 10° C.

What is the maximum density of water?

The general rule is for matter to expand on heating and contract on cooling. Water offers a partial exception. In heating water from 0° C. to 4° C. (32° F. to 39.2° F.) its volume *decreases.* Heating beyond this point, it will expand. So at 4° C. it will expand, whether you heat or cool it. Its density at + 8° C. would be equal to that at 0° C. Water is therefore said to be at its *maximum density* at 4° C.

What experiment shows this?

Take a deep vessel with a lateral aperture above and below; into each fix a thermometer. Fill the vessel with water at 0° C., and place it in a room warmer than that temperature. As the layers of liquid at the sides of the vessel become heated, they will sink to the bottom, and the lower thermometer will mark +4° C., while the upper one is still at 0°. This shows that water is heavier at 4°, its maximum density, than at 0°.

How is this phenomenon important in nature?

In winter the temperature of the lakes and rivers falls, the colder water sinks to the bottom, and there is a series of currents until all is reduced to +4° C. The cooling on the surface still continues, but

these layers, cooled between +4° and 0°, being lighter, remain on the surface and freeze when 0° is reached. The ice then protects the water below, which remains at 4° even in severest weather—a temperature which does not destroy fish or other inhabitants of water.

Expansion of Gases.

What is the coefficient of expansion of gases?

Gases are the most expansible of all bodies, and also the most regular. Solids and liquids have their own peculiar coefficients, varying with the substance and varying with the temperature.

But all gases have the *same coefficient*, and their expansion is *uniform at all temperatures and pressures.* (There is a slight deviation from this law at high temperatures.)

Under uniform pressure any volume of any gas is increased $\frac{1}{273}$ for each degree C., or $\frac{1}{491}$ for each degree F., that its temperature is raised. This is the single coefficient of expansion for all gases.

All the above statements are also true for air.

What is meant by absolute zero?

As a body of air on being heated increases $\frac{1}{273}$ of its volume for each degree, at +273° C. its volume will be doubled. Also, if it be cooled below 0°, its volume will diminish by $\frac{1}{273}$ for each degree, so that theoretically at —273° C. there would be no gas left—annihilation of matter. But long before it reaches that degree of cold the gas would change its state and become a solid, and then be no longer subject to Boyle's law. This point, however, of —273° C. or —459° F. (—491° + 32°) is called *absolute zero*, and temperatures reckoned from this point are called *absolute* temperatures.

What is the law of Charles?

The volume of a gas at constant pressure or the pressure of a gas at constant volume is directly proportional to its absolute temperature. The density of a gas being inversely as its volume, the density is therefore inversely as its absolute temperature. This is a familiar fact. Hot air is lighter than cold. Bad air, being warmed, is at the top of a room; let it out here, and let good air in at the bottom.

Forced ventilation can produce currents in any direction, and generally from top to bottom.

CHAPTER IX.

THIRD EFFECT OF HEAT.—CHANGE OF STATE.—VAPORS.—LATENT HEAT.

What is fusion?

The expansion of solids is limited. The repulsion of its molecules may be so increased that after a certain point the molecular attraction is no longer sufficient to retain the body in a solid state. *Fusion* takes place; that is, a body melts or passes from a solid to a liquid state. Freezing- and melting-points are practically the same.

Some substances, such as wood and paper, do not fuse, but decompose. Others have been considered *refractory* and incapable of fusion. Carbon is now the only one unconquered, but it has been softened so as to be flexible.

What are the two laws of fusion?

1. *Each solid has a definite fusing-point.*
2. *During fusion the temperature remains constant.*

Whatever be the intensity of the heat, from the moment fusion begins the T. of the body ceases to rise, and remains constant till fusion is complete. A thermometer in a bucket of ice does not change till the ice is all melted, as the heat is at work melting ice. That is, heat that changes the state of matter does not change temperature. It cannot both melt a substance and change temperature at the same time. Hg melts at —40° C.; hence is always fluid in our climate.

Butter melts or fuses at 33° C.
Phosphorus melts or fuses at 44° C.

Wax	"	"	65°.
Sulphur	"	"	110°.
Tin	"	"	230°.
Bismuth	"	"	562°.
Silver	"	"	1000°.
Gold	"	"	1250°.
Platinum	"	"	1775°.

Some substances pass from a solid to a liquid state, without showing any definite melting-point.

For example, glass and iron become softer and softer, and pass by degrees to a liquid condition. This intermediate condition is called a state of *vitreous fusion.*

This is a valuable property of pure iron in *welding.* Iron has peculiar qualities given it by different degrees of heat. There are three states of iron. Wrought iron, the first state, is 99.75% pure. Cast iron, the second state, is 95% pure. It contains some C and Si. Steel is the third state of iron, and is 98% pure.

What is the influence of pressure on the melting-point?

Pressure has practically no effect on the melting-point, being thus very different from its effect on the boiling-point.

Under pressure, however, the melting-point is raised a little for all substances which expand on passing from a solid to a liquid state. Such bodies have to do external work—viz. raise the pressure of the the atmosphere by their expansion. If the external pressure be increased above this atmospheric pressure, the power of overcoming it can only be obtained by an increase of the vis viva of its molecules; this means a higher T. The fusing-point is therefore raised.

In case of bodies which contract on passing from a solid to a liquid state, of which water is the best example, pressure *lowers* the melting-point. Melting ice has no external work to perform, no external pressure to raise, but in melting it transforms external work into heat, and so renders a smaller quantity of heat necessary.

A pressure of 8 atmospheres would only lower its melting-point $\frac{1}{16}°$ C.

What is an alloy?

An alloy is a mixture of two or more metals. An *amalgam* is an alloy of Hg with some other metal. Tin amalgam is the reflecting surface on the back of a mirror.

An alloy generally melts at a lower point of T. than either of its component metals. This melting-point is not a mean, nor does the most fusible metal melt first.

Newton discovered an alloy of tin, lead, and bismuth which melts at 94° C.

Tin melts at	230° C.	94° C., melting-point of all combined.
Lead melts at	320°	
Bismuth melts at	562°	

Cadmium plus Newton's alloy is Wood's alloy, and melts at about 66° C. It is used for filling teeth.

Brass	is an alloy of	Cu and Zn.
Britannia	"	Pb, Sb, and Sn.
Bronze	"	Cu and Sn.
German silver	"	Cu, Ni, and Zn.
U. S. silver coin	"	Ag 900, Cu 100 parts.
U. S. gold coin	"	Au 900, Cu 90, Ag 10 parts.
Pewter	"	Pb and Sn.
Type-metal	"	Pb and Sb.
Newton's metal	"	Bi, Pb, and Sn.
Wood's "	"	Bi, Pb, Sn, and Cd.

Fusible alloys are of use in soldering and taking casts. They have been used in making plugs for engines, answering the purpose of safety-valves.

What are fluxes?

Depending on the properties of alloys, fluxes are substances which when added to an ore help reduce it to its metallic state. It is called "sweating out" the metal.

What is latent heat?

We have seen that during the passage of a body from a solid to a liquid state, the temperature of that body does not rise until fusion is complete. It must be concluded that such a body absorbs considerable heat, which is only effective in maintaining it in a liquid state.

Such heat is said to become latent, and is not indicated by the thermometer. It is called the *latent heat of fusion* or *latent heat of fluidity*.

What is the latent heat of water?

It can be proven by experiment to be 79° C.; that is, 79 heat-units will disappear during the change of ice at 0° C. to water at same T.; according to Bunsen, 80.025 units.

If we take 1 lb. of water at 79° C., and 1 lb. of water at 0° C., the T. of the mixture will be the mean. But 1 lb. of water at 79° C. and 1 lb. of *ice* at 0° C. give a different result.

1 lb. water at	79° C.	or	174.2° F.
1 lb. water at	0° C.	or	32° F.
	2)79		2)206.2
2 lb. water at	39.5° C.	or	103.1° F.

One loses as much as the other gains. Now take

1 lb. water at	79° C.	or	174.2° F.
1 lb. *ice* at	0° C.	or	32° F.
Result is 2 lb. water at	0° C.	or	32° F.
Loss of	79° C.	or	142.2° F.

Apparently, 79° C. have disappeared. It has done work—viz. melted ice without raising its temperature.

This will be better understood if we put 1 lb. of *ice* at 0° C. in a beaker, and the beaker in a vessel of boiling water. At the same time put in the boiling water another beaker containing 1 lb. of *water* at 0° C. Note the T. in the two beakers at the moment all the ice is melted. It will be found that the T. of the ice-beaker has not changed, while the other has risen to 79° C. Both received the same amount of heat; hence the amount which disappeared in changing the state of ice was 79° C. This heat is not lost, for it will be given up when a reverse change takes place—when water becomes ice again. A thermometer cannot detect the difference between ice at 0° and water at 0°, though there are 79° difference. To cool off a patient most effectively, therefore, you would use pounded ice, and not ice-water, for the ice extracts 79° C. from him before it becomes ice-water.

Each substance has its peculiar degree of heat, which it makes latent.

Latent heat of	Hg	is	5° C.
" " "	Ag	"	21°.
" " "	Zn	"	28°.
" " "	H_2O	"	79.24°.

What will be the result of the following mixtures?

(1) 5 lb. of water at 142° F. = 710 heat-units.
3 lb. " " 32° F. = 96 " "
8 lb. water 8)806 heat-units.
100.7° F. Ans.

(2) 5 lb. water at 142° F.
3 lb. ice " 32°.

The water has 710 heat units. The ice will absorb $142 \times 3 = 426$ units in becoming water at 32°, leaving $710 - 426 = 284$ units. But 3 lb. water at 32° will have 96 units $+ 284 = 380 \div 8 = 47.5$° F. Ans.

What is the process of solution?

A body is said to dissolve when it becomes diffused through a liquid. It may be a chemical combination because (1) all liquids do not dissolve all solids as they would mechanically; (2) gravity is overcome.

Fusion, we saw, was produced by heat more or less directly applied. The dissolving liquid is called the *solvent*, and the resulting liquid is called a *solution*. When the adhesion between the solid and liquid is satisfied or balanced by the cohesion in the solid, the solution is said to be *saturated:* when the solution will take up much more of the solid it is *dilute*, and *concentrated* when it will take up none or but little more.

Heat generally weakens cohesion more than adhesion; so, with few exceptions, hot liquids dissolve solids more rapidly than cold ones. Water is the great solvent.

What changes of temperature occur during solution?

During solution, as well as in fusion, a certain quantity of heat becomes latent; hence the solution of a substance produces a diminution of T. In certain cases, however, the T. actually rises, as when caustic potash is dissolved in water.

But here are two opposite phenomena. One is the change of the solid to a liquid state, which always lowers T.; the other is a chemical combination, which raises T.; and as one or the other of these two effects predominates, or as they are equal, the T. either rises or sinks or remains constant. If we put sulphocyanide of ammonium into hot water, the temperature will fall below the freezing-point. The water has to give up all its heat to make the substance liquid.

What is solidification or congelation and its laws?

Solidification is the passage of a body from a liquid to a solid state. Its laws are analogous to those of fusion.

1. *A liquid cannot solidify until it has reached a fixed T.—viz. its freezing-point—and this varies for each liquid.*

2. *The temperature remains constant from the commencement to the end of solidification.*

A third law might be added: *A liquid cannot solidify until all the latent heat is out of it.*

Certain fats after repeated fusions seem to undergo a molecular change which alters their melting-point; hence an exception to the first law in regard to a fixed T. for each liquid. The latent heat absorbed during fusion becomes free at the moment of solidification. Farmers understand this, and keep a barrel of water in their root-cellar. It serves as a reservoir of heat. Water on freezing gives out a great deal of heat—at a low T., it is true, yet high enough to protect the vegetables.

What is crystallization?

Crystallization is due to the property of polarity, and is a process of solidification. Nearly all substances crystallize in passing from a liquid to a solid state. Nobody knows why some minerals and some complex organic bodies, like albumins, will not crystallize. Such substances are *colloids.*

If crystals are formed from a body in fusion, as sulphur or bismuth, the process is said to take place by the *dry way.* Crystals are formed better in the slow process of cooling or by slow evaporation. This is the *moist way.* Some crystals in nature weigh tons. Beryl, a faded emerald, is an example.

What conditions may retard the point of solidification?

If a liquid is placed under peculiar conditions, it may be cooled several degrees below its freezing-point and not solidify—a curious state of unstable equilibrium, called *surfusion.*

Place water freed from air by boiling in a clean vessel, and it may be cooled to —15° C. without freezing. It has to be started by agitating it or putting in something for a nucleus, like a grain of sand, when it freezes at once. Such solidification takes place very

rapidly, and is sufficient to raise the T. of the liquid up to the ordinary freezing-point, when solidification is completed.

Rapid agitation prevents the formation of ice.

Water in capillary tubes can be lowered to —20° C. without freezing; thus sap may remain unfrozen in the capillary vessels of plants in severe weather. Powerful pressure retards the freezing of water, probably by opposing its tendency to expand.

Salts in solution or foreign bodies lower the freezing-point. Sea-water freezes at —3° C. (27° F.). Its ice is quite pure, leaving a saturated solution behind.

What change of volume takes place on solidification or liquefaction?

The expansion of bodies generally increases as they approach their melting-points, and this is followed in most cases by a further expansion at the moment of liquefaction, so that a liquid occupies a greater volume than the solid from which it was formed; hence it is lighter. Water presents a remarkable exception: it expands at the moment of solidifying, so that 10 parts of water go to form 11 parts of ice; therefore ice floats, having a greater volume. An iceberg is about $\frac{1}{11}$ out of water and $\frac{10}{11}$ under water.

The sp. gr. of ice is .9178. This increase of volume in forming ice is accompanied by an almost irresistible force, which is one of the most powerful agents of nature and a most lucrative source of income to the plumber. It splits stones, moves rock-beds, and disintegrates the earth's surface.

Major Williams of Canada filled an iron bombshell with water, and firmly closed the vent with an iron plug weighing 3 lb. He exposed it to the frost of his country, and after a while the plug was thrown 415 feet with a loud explosion.

Cast iron and Bi expand on cooling like water. Pb and Sb contract, yet an alloy of these two—viz. type-metal—expands and fills moulds.

What is the principle of freezing mixtures?

The absorption of heat in the passage of bodies from a solid to a liquid state has been used to produce artificial cold. So-called *freezing mixtures* are used—either two solids or a solid and a liquid which have chemical affinities for each other. It is a chemical operation,

and if the solid can get heat enough from its surroundings, it will liquefy, and its neighbor will freeze, being robbed of its heat. When we mix about 2 parts of snow or pounded ice with 1 part of common salt, the affinity of salt for water liquefies the ice, and the resulting liquid dissolves the salt, both operations requiring heat from elsewhere. This will give a T. of —18° C. Chloride of calcium and snow in parts of 2 to 3 will produce a T. of —45° C. and will freeze Hg. Sulphocyanide of ammonium is also a most remarkable freezer.

Vapors.

Define vapor.

A vapor is an aëriform fluid easily changed to a liquid; it is an easily condensible gas. A gas is not so easily changed.

Volatile liquids are those which possess the property of passing into an aëriform state, as ether or alcohol. *Fixed liquids* do not form vapors at any temperature without undergoing chemical decomposition; such are the fatty oils. *Fatty* or *fixed* and *essential* or *volatile* are the terms used.

Some solids, like ice, camphor, or carbonate of ammonium, and in general all odoriferous substances, pass directly into a state of vapor without first becoming a liquid. The condensed vapor is a *sublimate.*

Definitions.

Vaporization is the general term by which to designate the passage of any substance into a vapor or gas.

Evaporation means the slow production of a vapor or gas at the free surface of a body, solid or liquid.

Boiling or *ebullition* is the rapid production of vapor in bubbles throughout the mass of the liquid itself—bubbles from the bottom of the liquid in boiling; bubbles from the top of the liquid in evaporation.

The singing of the tea-kettle is due to the condensation of steam from the lower strata by the upper colder layers.

Heat hastens evaporation. It takes place over a wide range of T. It has no fixed point, and may take place with the same liquid at very different temperatures, though there are limits below which it does not occur. Hg is said not to evaporate below 0° C.

Define boiling-point.

Boiling, on the other hand, takes place at a fixed T., and the *boil-*

ing-point of a liquid is that point where the tension or pressure of its vapor equals the pressure it supports.

A colorless gas is invisible, though a colorless liquid is not, due to its different refractive powers. Five gases have color—Cl, Br, I, and two of N. Vapors are transparent like gases, and usually colorless. Steam is colorless, and consists of bubbles of water in air. Only a few colored liquids give off colored vapors.

Do vapors have elastic force?

Vapors have elastic force like gases, and exert pressures on the sides of the vessels in which they are contained. This tension varies with different vapors. Cold and pressure convert the vapor into a liquid, and, on the other hand, heat converts the liquid back into a vapor.

What are the laws for formation of vapors in vacuo?

Put into Torricellian vacua various liquids, as a few drops of water, alcohol, and ether into B, C, and D of Fig. 36. A stands as a barometer. When the liquid reaches the vacuum, instantly the column of Hg falls. This cannot be due to the weight of the few drops of liquid introduced, but rather to the formation of some vapor whose elastic force has depressed the Hg.

FIG. 36.

The depression is greater for alcohol than for water, and greater for ether than for alcohol.

We consequently obtain two laws:

1. *In a vacuum all volatile liquids are instantaneously converted into a vapor.*

2. *At the same temperature the vapors of different liquids have different elastic forces.*

What is a saturated vapor?

Suppose we continue to add ether to D until it ceases to vaporize and remains liquid. The depression of the Hg column also ceases, and the space is said to be saturated. A vapor that is in contact with its parent liquid is *saturated.*

Does a saturated vapor obey Boyle's law?

There is a limit to the tension of a saturated vapor. To show there is a maximum of tension which the vapor cannot exceed, dip a barometric tube in a deep bath of Hg. Add ether in excess to the Torricellian vacuum. Note the height of the Hg column, and now, whether the tube be depressed, which tends to compress the vapor, or whether it be raised, which tends to expand it, the height of the column of Hg is constant; only the length of the space above changes.

When this saturated vapor is compressed, a portion returns to the liquid state; when pressure is diminished, a portion of the excess of liquid vaporizes, and in both cases the tension and density of the vapor remain constant, therefore disobeying Boyle's law.

How do unsaturated vapors behave?

A *non-saturated* vapor behaves exactly like a gas, and is subject to Boyle's law.

If in the above experiment we introduce only a little ether, so its vapor is not saturated, and then raise or depress the tube, the Hg column will rise and fall, showing that the elastic force of the vapor diminishes and increases "inversely as the pressure." Whenever unsaturated vapor is heated, it expands like a gas. Ordinary gases are not saturated, and we may define a gas as an unsaturated vapor. Every gas is the vapor of some liquid; only vapors are easily turned back, and a gas is not; *e. g.* oxygen gas.

What can be said of the tension of aqueous vapor?

Even below zero, water evaporates; aqueous vapor is present, and has tension. If water at 0° C. be introduced into a Torricellian vacuum, its vapor will depress the Hg column 4.54 mm.; at —30° C. the depression will be 0.36 mm.

The reason that water does not boil in an open vessel below 100° C. is, that the tension of its vapor cannot lift the weight of the atmosphere. Above 100° C. the tension is measured by a manometer or pressure-gauge, and the corresponding T. has been determined by experiment. If the pressure show 105 lbs. to the sq. in.—that is, 7 atmospheres (7×15)—it would correspond to 165° C.

100.0° C.	corresponds	to a	pressure	of	1	atmosphere.
120.6° "	"	"	"		2	atmospheres.
133.9° "	"	"	"		3	"
152.2° "	"	"	"		5	"
180.3° "	"	"	"		10	"
213.0° "	"	"	"		20	"

The tension of vapors of mixed liquids may be equal to the sum of the two taken separately if the liquids have no solvent action on each other. If they dissolve in all proportions, the combined tension is an intermediate one.

What causes affect the rapidity of evaporation?

The evaporations from seas, lakes, soil, etc. rise in the atmosphere, form clouds, condense, and fall as rain. Air does not take up vapor like a sponge, for if it were wholly removed there could be just as much aqueous vapor present.

Four causes influence the rapidity of evaporation:

(1) Temperature;
(2) Quantity of the same vapor in the surrounding atmosphere;
(3) Renewal of this atmosphere;
(4) Extent of surface.

(1) Increase of T. accelerates evaporation by increasing the elastic force of vapors. (2) No evaporation could take place in a space already saturated with the vapor of the same liquid. (3) is similarly explained, for if the air or gas which surrounds the liquid is not renewed, it soon becomes saturated and evaporation ceases. Note the old lady drinking tea: she pours it into her saucer to get extent of surface (4), and blows upon it for renewal of atmosphere.

The above causes hold good for evaporation in vacuo.

What are the laws of boiling?

1. *Pressure raises the boiling-point of all substances.* 2. *The temperature at which liquids boil differs for different substances, but is invariable for the same substance if the pressure is constant.* 3. *During the process the temperature remains constant until all is vaporized.*

The boiling-point under one atmosphere is

37° C.	for	ether.
78° "	"	alcohol.
100° "	"	distilled water.
117° "	"	acetic acid.
325° "	"	sulphuric acid.

It has been shown that in an homologous series of fatty acids each difference in composition of CH_2 is attended by a difference of 19° C. in the boiling-point.

What is the effect of substances in solution on the boiling-point?

The boiling-point of water is raised by the presence of salts in solution; acids also have the same result; but substances mechanically suspended, as bran or shavings, do not affect it. A saturated solution of common salt does not boil till 102° C. is reached. Salt nas affinity for water, and the extra 2° are required to overcome this affinity. The absence of dissolved air exerts a marked influence. Water that has been freed from air by prolonged ebullition can be raised to 135° C. without boiling; or boiled-out water covered by a layer of oil can be raised to 120° C., when it suddenly begins to boil with almost explosive violence.

What effect does the nature of the vessel have on the boiling-point?

It has something to do, depending upon whether its surfaces be dirty and rough or smooth and clean; the latter condition retards boiling.

If water boils in a copper vessel at 100°, it will boil in a glass one at 101°; and if the glass had been previously cleaned by H_2SO_4 and potash, the T. could be raised to 105° or 106° without boiling. After it begins to boil, the T. goes down at once to the normal boiling-point. Whatever be the boiling-point of the water, the T. of its vapor is uninfluenced by the nature of the vessel. The vapor, however, of boiling saline solutions is probably the same as that of pure water.

How may the influence of pressure be shown? (Franklin's exp.)

Pressure is the controlling condition. As pressure increases or diminishes, the tension of the vapor, and therefore the T. necessary for ebullition, must increase or diminish. A liquid may have an

indefinite number of boiling-points. Place a dish of warm water under the receiver of an air-pump. As the air is exhausted the liquid begins to boil, when the tension of its vapor can overcome that of the rarefied air. Heat and cold can sometimes have the same effect, thus: Boil water in a glass flask, and when all the air has been expelled by steam, cork it and invert as in Fig. 37. If the bottom be now cooled by cold water, the inside vapor will condense, and so diminish the pressure that the liquid boils.

FIG. 37.

In consequence of this diminution of pressure water boils on high mountains at temperatures lower than 100°—on Mont Blanc at 84° C.; in Quito, S. A., at 90° C.

What is the principle of the vacuum-pan?

This principle of rapid evaporation under feeble pressures is made use of in refining sugar and condensing milk and preparing some medicinal extracts.

The syrup, for instance, is put into an air-tight vessel, called a *vacuum-pan*, which is exhausted by a steam air-pump, and evaporation goes on at a low T., which does not injure the syrup. Five quarts of milk are made into one of condensed milk.

On the other hand, by increasing the pressure to 2 atmospheres water only boils at 120° C. The fluid in the *pulse-glass* and some toys boils on the above principle of reduced pressure.

What is the water-hammer?

All natural water has air and other gases in it. When these are boiled out, the water resounds on the sides of the vessel, constituting a *water-hammer*. Such boiled-out water behaves in a peculiar fashion. A sudden burst of steam may occur from such water, thus perhaps explaining some boiler explosions.

What is the boiling-point of a mixture?

The boiling-point of a mixture depends on the proportion of each

ingredient. If the two liquids mix in all proportions, as alcohol and water, then their boiling-point is the mean; which is not the case with unequally mixing liquids.

How may heights be measured by the boiling-point?

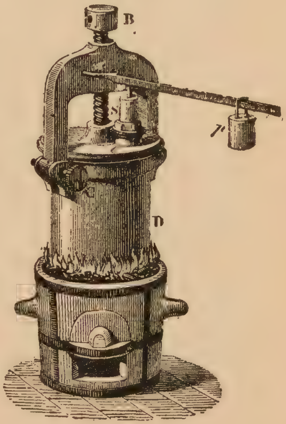
We may find out the heights of mountains, using the thermometer instead of the barometer. Suppose water boils at 90° on the top of a mountain, and at 98° at its base. Tensions of aqueous vapors for different temperatures have been determined, and so the tensions for these temperatures are sought in tables. They will give barometric heights, and from these the height of the mountain can be calculated.

An ascent of about 1080 ft. produces a diminution of 1° C. in the boiling-point, or 600 ft. for 1° F. The instruments used for this purpose are called *thermo-barometers* or *hypsometers*, and they determine heights by means of the boiling-point to within about 10 ft.

What is the critical point or temperature?

It is that T. above which no amount of pressure can prevent a liquid from going into a gaseous state. If alcohol which half fills an hermetically-sealed tube be subjected to sufficient heat, a moment is reached at which the liquid suddenly disappears and is converted into vapor at 207° C. This is its *critical point*, and below it there is a sharp line of demarkation between the liquid and the gas; above it is perfect continuity between the two, and vapors above the critical temperature are permanent gases.

Fig. 38.



Describe Papin's digester and its uses.

Papin's digester is a contrivance with an opposite principle to that of the vacuum-pan, and is used for boiling under pressure in closed vessels. Patent *soup-kettles* are for the same purpose, and useful where a higher T. than 100° is required. The digester consists of a cylindrical iron vessel with a cover fastened

by a screw B (Fig. 38). At S is a safety-valve arrangement regulated to any desired pressure. The cylinder is filled about two-thirds full of water, for example, and placed over a fire. The T. of the water may thus be increased far above 100°, and the tension of its vapor raised to several atmospheres. On high mountains water boils at such low T. in open vessels that the degree of heat is not sufficient to soften animal fibre and extract the nutriment. Eggs are said not to cook by boiling on top of Mont Blanc. So the digester is used for preparing food, and also for the extraction of gelatin from softened bones.

Explain the latent heat of vapor.

As the T. of a liquid remains constant during boiling whatever be the source of heat, it follows that a considerable quantity of heat must be absorbed, the only effect of which is to change the liquid into a gas. Conversely, when the saturated vapor passes back to the liquid state, this latent heat is given up and becomes *sensible* heat. Such heat is called the latent heat of evaporation, analogous to that of fusion. There is an enormous amount of it in vapor which does not show itself by a thermometer. It does great internal work in overcoming the cohesion among the liquid molecules, and in causing them to separate and repel each other, as they do in a gas. The latent heat of steam—properly speaking, of water at 100° C.—is 535.9 calories. Every substance has its own peculiar latent heat. For alcohol vapor it is 208°, for ether it is 90° C. This means that as much heat would be required to convert 1 lb. of water at 100° to a vapor at 100° as would raise 1 lb. of water through 536°, or 536 lb. through 1°.

Steam-heating is made possible by using this latent heat; the steam, condensing, gives up its 536° previously received.

Watt, who investigated this subject, thought that latent heat was a constant quantity—*i. e.* the lower the T. the greater the latent heat, and *vice versâ*.

Regnault found that the total quantity of heat necessary for the evaporation of water *increases* with the T., and is not constant, as Watt had supposed. He represented it by this formula:

$$Q = 606.5 + 0.305\, t,$$

where Q is the total quantity of heat at the temperature of the

water during evaporation, and the numbers are constant quantities. The quantity of heat, therefore, necessary to evaporate water at 100° is $606.5 + (.305 \times 100) = 606.5 + 30.5 = 637°$. At 150° it would be $606.5 + (.305 \times 150) = 652.25°$.

As the boiling-point rises the latent heat increases.

Show how cold is produced by evaporation.

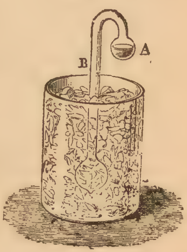
Whatever be the T. at which a vapor is produced, an absorption of heat always takes place. If this heat cannot come from without, it comes from the liquid itself, and its cooling is greater in proportion as the evaporation is more rapid.

Water may be frozen thus: under the receiver of an air-pump place a vessel of strong H_2SO_4, and over it a thin glass capsule containing water. By exhausting the receiver the water begins to boil, and the vapor is absorbed by the acid as fast as it is formed. Rapid evaporation being effected, the water quickly freezes by parting with heat sufficient to produce its vapor.

Explain the cryophorus.

Wollaston's cryophorus consists of a bent glass tube with a bulb at either end. A small quantity of water is introduced and boiled to expel the air. It is then hermetically sealed, and contains only water and vapor of water. The water is in bulb A (Fig. 39), and the other bulb is immersed in a freezing mixture. The vapors are thus condensed, and the water in A yields more. But this rapid production of vapor requires heat, which is abstracted from the water in A until its T. is so reduced that it freezes.

FIG. 39.



Again, if water in a test-tube be placed in a vessel of ether and the evaporation of the ether be hastened by a bellows, the water in the tube can be frozen. Hg can be frozen by evaporating liquid SO_2 around it.

Some of the means for producing local anæsthesia depend on the cold produced by the evaporation of volatile substances, as rhigolene spray or a mixture of chloroform, menthol, and ether.

The cooling effect produced by a wind does not arise from the

wind being cooler—it may even be warmer—but it is due to the rapid evaporation on the surface of the skin.

Water is cooled in hot countries by placing it in porous earthern vessels, called *alcarrazas*. The water percolates through the sides, so that there is a continual evaporation on the outside, cooling the contained water.

What is the principle of ice-machines?

Ice-making and cold-producing machines depend upon the principle of taking away the latent heat of water; which heat is all that prevents it from being a solid and only keeps its molecules in motion.

What is Harrison's method?

Harrison uses the rapid evaporation of ether produced by a steam air-pump. In the ether is immersed the vessel of water to be frozen. The vaporized ether can be condensed and used again.

Describe Carré's ice-machine?

This apparatus depends upon the distillation of ammonia. A boiler C is connected with the freezer A by a stout tube (Fig. 40).

FIG. 40.

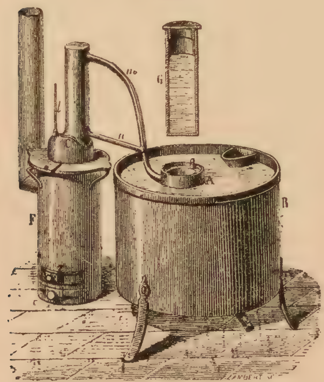
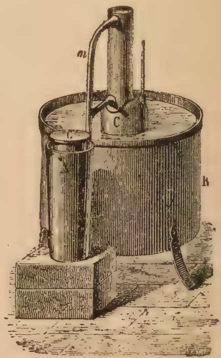


FIG. 41.



The freezer has two concentric envelopes, the annular space alone communicating with the tube from C. Ice is formed by two distinct

operations: First, the boiler, containing a strong solution of ammonia, is placed on a furnace F and heated to about 130° C., and the freezer is placed in cold water. The ammoniacal gas is disengaged from F, and by virtue of its own pressure is liquefied in the annular space of A. This distillation lasts for about an hour and a quarter. Next, the boiler is put in cold water, and the freezer outside (Fig. 41), which contains the vessel G, about three-fourths full of the water to be frozen. As the boiler cools its internal pressure is lessened, and the liquid ammonia in A becomes gaseous and passes to C. In becoming vaporized it requires a great deal of heat, and takes it from G, and in about an hour and a quarter a block of ice can be removed.

A large apparatus of this kind can produce 800 lb. of ice per hour, at the cost of less than $\frac{1}{4}$ cent per lb.

Carré has also constructed another ice-machine, where the water to be frozen and H_2SO_4 are placed under the receiver of an air-pump. The rate of the freezing depends upon the strength of the acid. Water in the carafes of hotel dining-rooms may be thus frozen, many water-bottles at a time being placed under the receiver of a steam air-pump. Large freezing-machines cost $100,000 or more.

Cold-producing machines are used in breweries, for beer is fermented at a low T. The storehouse for beer is a large cool cellar called the *lager*.

Machines for cooling large spaces depend upon the fact that expansion of gases produces cold. Compressed air allowed to expand may fall in snowflakes. Such device is used in the meat-rooms of ocean steamers.

How may vapors be liquefied?

The liquefaction or condensation of vapors is their passage from an aëriform to a liquid state, and may be accomplished by three means:

$\left.\begin{array}{l}\text{1. Cooling}\\ \text{2. Pressure}\end{array}\right\}$ for saturated vapors only;

3. Chemical affinity, saturated or unsaturated.

When vapors are condensed their latent heat becomes free and affects the thermometer.

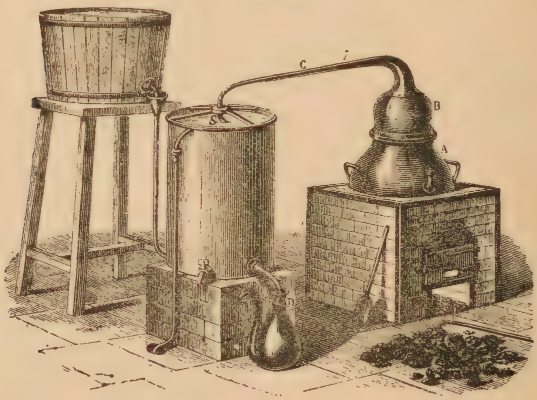
What is distillation?

Distillation is an operation by which a volatile liquid may be separated from a solution, or by which two liquids of different volatilities may be separated. It depends upon the vaporization of liquids by heat, and upon the condensation of those vapors by cooling, and is possible from the fact that the boiling-points of different substances differ.

Describe a still.

A still is the apparatus used for distillation, and it consists essentially of (1) a copper *body* A (Fig. 42) containing the liquid and fitting upon a furnace. (2) The *head* B connects with (3) the *worm* S. This is a long spiral tube placed in a bath of running water. It

FIG. 42.



offers a large extent of cold surface, and condenses the vapor. The surrounding bath of water becomes heated and runs out at the top, and cold water runs in from the bottom.

If a volatile liquid like alcohol is to be separated from water, the mixture is heated to the boiling-point of alcohol, and not to that of water, which is for the most part left behind. When ships lose their fresh water, they can distil that of the briny deep. The salt remains behind in the body of the still.

What is Liebig's condenser?

This is a still used for laboratories, and consists of a glass retort and a condensing part. The latter is a straight tube surrounded by running water.

Define sublimation.

Distillation applies to liquids, sublimation to solids; it is a distillation whose product is a solid. If this product is compact, it is called a *sublimate;* if slightly cohering, it is called *flowers*, as flowers of sulphur.

Corrosive sublimate gets its name from the fact that mercuric sulphate and common salt are sublimed—*i. e.* are raised by heat to a state of vapor—and the result of the condensation is mercuric chloride (corrosive sublimate) and sodium sulphate. Thus:

$$HgSO_4 + 2NaCl = HgCl_2 + Na_2SO_4.$$

Calomel, the mild chloride, is also a product of sublimation from mercurous sulphate.

Fractional distillation is the collection of separate distilled portions between certain temperatures.

How may gases be liquefied?

A saturated vapor, the T. of which is constant, is liquefied by increasing the pressure, or, pressure being constant, it is liquefied by lowering the T.

Unsaturated vapors may be brought to the state of saturation, and then liquefied by either diminishing the T. or increasing the pressure. As gases are mostly far removed from the point of saturation, both cold and pressure are required for their liquefaction. Unless you cool a gas down to a certain T., you cannot liquefy it by any amount of pressure. O_2 was liquefied at —130° C. and at 475 atmospheres.

Every gas has its critical T. and its critical pressure, and it cannot be liquefied if it is above its critical T.

How did Faraday liquefy gases?

Faraday's method was to enclose in one arm of a bent glass tube substances whose chemical action would disengage the gas to be liquefied. In proportion as the gas is evolved, its pressure increases, and it ultimately liquefies and collects in the shorter arm, more espe-

cially if this arm be placed in a freezing mixture. Sulphurous acid gas can be thus liquefied by placing copper and sulphuric acid in the long arm:

$$Cu + 2H_2SO_4 = CuSO_4 + SO_2 + 2H_2O.$$

Sulphuric acid and carbonate of sodium in the long arm produce CO_2, which is liquefied in the short arm.

Liquid CO_2 and N_2O (laughing gas) fall in flakes like snow when escaping from a tube, and together will produce a cold of —166° C. by evaporation; —210° C. is obtained by evaporating liquid air.

Krupp made use of the evaporation of liquid CO_2 to reduce the temperature of old cannon, and thus enable him to get the "re-enforce" off the gun. Four gases are liquefied for commercial use—NH_3, SO_2, CO_2, and N_2O.

What are Dalton's laws of the mixture of gases and vapors?

1. *The pressure and the quantity of vapor which saturates a given space are the same, whether this space contains a gas or is a vacuum.*
2. *The tension of the mixture is the sum of the tensions of each.*

Discuss the spheroidal state.

The phenomena of liquids thrown upon incandescent metals were observed by Leidenfrost a century ago. When a drop of water is thrown upon red-hot platinum, it does not spread itself nor moisten the dish, but assumes the form of a flattened globule. It has passed into the spheroidal state.

The globule rests upon a cushion of its own vapor produced by the heat radiating to its under side. If the platinum cools, not enough vapor is formed to buoy up the globule, and it now touches the metal and is rapidly dissipated. All volatile liquids can assume this condition. For water the dish must have a T. of 200° C.

The T. of liquids in this state is always below their boiling-points. Take, therefore, some liquid SO_2, whose boiling-point is —10° C., and place it in a red-hot platinum dish. It assumes the spheroidal state, with a T. perhaps of —11° C. If the same quantity of water is added, the SO_2 is vaporized, getting its heat from the water, which is consequently solidified. By a little dexterity a lump of ice may be thrown out of a red-hot crucible.

Experiments on this state explain the fact that the hand may be

dipped into molten lead or iron without injury. The natural moisture of the hand acts as a cushion of vapor, preventing contact of metal and skin. The tales of ordeals by fire in the Middle Ages, of men who could run barefooted over red-hot iron and not be burned, are possibly true, and here find an explanation.

What is the density of vapors?

The density or specific gravity of vapors is the relation between the weight of a given volume of this vapor and that of the same volume of air or of H gas, temperature and pressure of course being the same. The density depends upon the chemical composition, and is $\frac{1}{2}$ the weight of the molecule on the H unit, or $\frac{1}{28.86}$ of the molecular weight on the air unit.

So we can always find the sp. gr. of a gas if we know its formula and atomic weights. (See pp. 48, 49.)

CHAPTER X.

HYGROMETRY.

What is hygrometry?

It is the science of moisture, and its province is to determine the quantity of aqueous vapor contained in a given volume of air or to obtain the percentage of saturation.

The hygrometer is an instrument used for this determination.

What is the hygrometric state?

The hygrometric state, or degree of *saturation*, is the ratio of the quantity or elastic force of aqueous vapor actually present in the atmosphere to that which it would contain if it were saturated. In general, the air is never saturated.

The *absolute moisture* is the weight of water actually present in the form of vapor in the unit of volume.

So we may judge the amount of moisture present in two ways; (1) by getting the actual amount; (2) by getting the ratio in percentages.

What is the hygroscope?

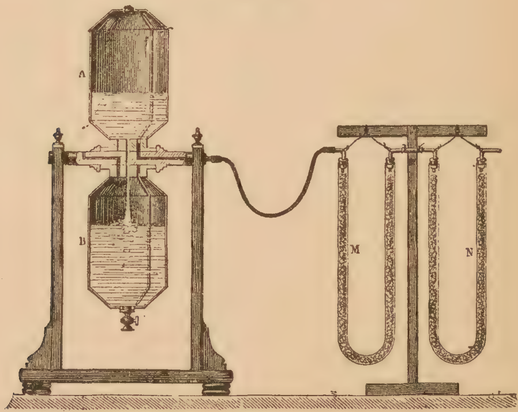
The hygroscope is an instrument simply showing whether air is moist or dry. The chloride of cobalt does this: when dry it is pink, turning red when moist. From the nitrate or chloride of this metal the toy ballet-dancer is made, changing color according to change of weather.

Fibres of various kinds are hygroscopic, elongating when moist and shortening when dry. Wool, hair, and paper have affinity for moisture.

What is the dew-point?

The dew-point is that T. at which air is saturated, or it is the T. at which moisture is first deposited from the surrounding air. Fill a pitcher with ice-water, and the layer of air in contact with the pitcher cools until a point is reached at which the vapor present in air is just enough to saturate it. The least diminution of T. causes the moisture to be precipitated on the pitcher in the form of dew. If the object on which dew falls is below zero, the dew freezes and *frost* results.

FIG. 43.



Describe the different varieties of hygrometers.

(1) Chemical;

(2) Condensing, as Daniell's dew-point hygrometer;

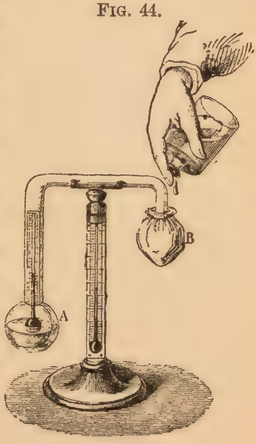
(3) Psychrometers, as wet- and dry-bulb hygrometer;
(4) Absorption hygrometers.

(1) The method of the *chemical hygrometers* consists in passing a known volume of air over a substance which readily absorbs moisture—*e. g.* chloride of calcium. The substance having been weighed before the passage of air, and then afterward, the increase in weight represents the amount of aqueous vapor present. Two brass aspirators A and B (Fig. 43) act alternately. The lower one is always in connection with the air, while the upper one is connected with the two tubes M and N filled with $CaCl_2$. N absorbs the vapors to be weighed, and M stops any which might come from the reservoirs. The lower reservoir being full of water, and the upper one of air, the apparatus is inverted. A partial vacuum forming in A, air enters by N M. When all the water is run into B, it is again inverted, and another measure of air is drawn through. We can thus find the amount of vapor in a definite volume.

(2) *Condensing hygrometers* are *dew-point* hygrometers. Daniell's and Regnault's belong here.

Daniell's hygrometer consists of two glass bulbs at the ends of a tube bent twice. The bulb A is black and filled two-thirds full of ether, while B and the tube are full of the vapor of ether. A thermometer dips into A. Bulb B is covered with muslin, and ether is dropped upon it, which by evaporation cools this bulb. The internal tension is thus diminished, and the ether in A vaporizes, which cools this bulb. The layer of air in contact has its T. so lowered that it becomes saturated and deposits a ring of dew. The T. of this point is noted by the thermometer inside. The addition of ether to B is stopped, and as the T. of A rises the dew disappears. This point is also noted, and the mean of the two is the dew-point. The T. of the air is taken by the thermometer on the stem.

FIG. 44.



As the hygrometric state is the ratio of the pressure of the vapor actually present to the pressure that air could have at saturation, we find these pressures from tables. Suppose the T. of air at saturation—viz. dew-point—was 5°; the corresponding tension is 6.534 mm. Suppose the T. of air was 15°, its tension would be 12.699. Divide the former by the latter, and we have 0.514 for the hygrometric state, or, as percentage expresses it better, 51.40%, over half saturated.

A proportion gives the same

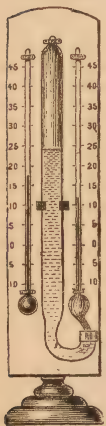
$$12.699 : 6.534 :: 100\% : x\,(51.40\%).$$

Saturated air at 70° F. contains $1\frac{1}{2}$% by weight of moisture. In summer the dew-point is rarely more than 33° F. below the atmospheric T.

Regnault's hygrometer is on the same principle as Daniell's, and is freer from sources of error. The readings are made by a telescope, so that the observer's body-T. may not modify the result.

(3) The *psychrometer*, or wet-bulb hygrometer, depends upon the principle that a moist body evaporates in air more rapidly in proportion as the air is drier. In consequence of such evaporation, the T. of the body sinks. Two thermometers are placed on a wooden stand (Fig. 45). One bulb is covered with muslin, and kept continually moist by a string leading from a reservoir of water. As the other bulb is dry, we may call this the *wet-* and *dry-bulb* hygrometer. Unless the air is saturated, the thermometer with the wet bulb always indicates a lower T. than the other, and the difference between the indications of the two thermometers is greater in proportion as the air can take up more moisture. A formula is devised and tables are furnished for getting the degree of percentage saturation.

FIG. 45.



(4) *Absorption hygrometers* are based on the principle that organic substances elongate when moist and contract as they become dry. The *hair hygrometer* is the most common form, and is only a hygroscope. A hair is turned around a pulley, and supports a small weight; its upper end is

fastened by a clamp. On the pulley there is a needle moving over a graduated scale. Various mantelpiece ornaments belong to this class. Their indications are always behindhand, and not exact.

How does moisture affect the death-rate, etc.?

Air is dry or moist according as it is more or less distant from its point of saturation. Our judgment is independent of the absolute quantity present.

Summer air containing 13 gm. of aqueous vapor to the cubic metre is very dry, as it could contain 22 gm. If winter air of the same volume contained 6 gm., it would be very moist, for it is nearly saturated.

When a room is warmed the quantity of moisture is not diminished, but the humidity of the air is lessened, because its point of saturation is raised. The discomfort to us depends more upon the degree of saturation than upon the T.

Air at 100° F. and partly saturated is better borne than air at 70° F. and fully saturated, in which latter case evaporation of perspiration is hindered.

The high death-rate among children in large cities, especially in July and August, is due to the combination of high T. and a high degree of saturation. This causes gastro-intestinal disorders and cholera infantum, and milk, their chief food, readily undergoes fermentation.

If a country has a low T. and high humidity, there is an increase of pulmonary diseases.

CHAPTER XI.

TRANSMISSION OF HEAT.

How may heat be transmitted?

By—

1. Conduction;
2. Convection;
3. Radiation.

Conduction, as from one end of a rod to the other; convection, by currents in liquids or gases—the molecules travel; radiation, as the sun radiates or emits both heat and light.

Discuss the conductivity of solids.

Good conductors are those which readily transmit heat. *Bad conductors* transmit it, but not readily. The conducting powers of metals are all different. This may be seen by fastening glass balls or marbles with wax to the ends of iron, copper, wood, and glass rods. These rods are made to receive each the same amount of heat, and the balls drop off in the order of the conductivity of the substances. Silver is the best conductor, and if it be represented by 100, other metals follow, thus:

Ag	100.
Cu	73.6.
Au	53.2.
Sn	14.5.
Bi	1.8.

Non-metallic substances are poor conductors. Wood conducts better in the direction of the fibre than transversely.

What can be said of the conductivity of liquids?

This is very small, as may be seen in boiling the top layers of water in a test-tube, while ice at the bottom is unmelted.

Water is a better conductor than glycerin, and alcohol is $\frac{1}{9}$ as good as water. Hg is the best of all. Calling the resistance of transmission in—

Water 1,
Glycerin is 3,
Alcohol is 9,
Chloroform is 10.

Do gases have conductivity?

This is a disputed point. Their conductivity is certainly small. Hydrogen, however, offers an exception, conducting seven times as well as air, but only $\frac{1}{20000}$ as well as Cu, indicating the metallic nature of H.

Heat is propagated in gases by convection.

Ag is the best conductor among solids.
Hg is the best conductor among liquids.
H is the best conductor among gases.

What are some of the applications of non-conductivity?

Felt is not the non-conductor, but the imprisoned layer of air; so if we wish to keep a body either cold or warm, we surround it with a cap of felt or pack it with straw or shavings. Cold- and hot-water pipes are thus wrapped. The molten slag of a blast-furnace can be utilized by passing steam through it, making mineral wool or "Pele's hair." Double windows keep a room warm by the interposed layer of non-conducting air. The clothes we wear are not warm of themselves; they only hinder the body from losing heat by the layer of air confined between them or in their meshes. Two shirts are warmer than one of double thickness. Linen is coolest because compact; eider-down warmest of all. Lava has been known to flow over a layer of ashes beneath which a bed of ice was not melted. A red-hot iron can be held in the hand if asbestos be interposed. When we touch iron or marble, they seem colder than they really are, for they readily conduct heat from us. Wooden floors are warmer than stone ones.

What is convection?

When a column of liquid or gas is heated at the bottom, ascending and descending currents are produced. The heat is thus distributed, and not much by conductivity. The lower heated layers expand, and, being less dense, rise in the centre of the mass, and are replaced by cooler layers falling down the sides. These currents may be made visible by putting bran in the water.

Radiation of Heat.

What is radiant heat?

It is that which can be transmitted to a body from the source without altering the T. of the intervening medium.

If we stand near a fire, the sensation of warmth is not due to the T. of the air; for if a screen be interposed, the sensation disappears. Hence, bodies can send out rays which penetrate the air without heating it, as rays of light penetrate transparent bodies. The sun's heat reaches us in this way. Heat travels by luminiferous ether, and the laws of heat and light are the same.

We can see the direction of light-rays, but with heat the direction has to be determined by delicate apparatus.

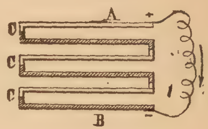
How is radiant heat detected and measured?

Delicate thermometers may be used, or, since electrical apparatus is so perfect, we may transform heat into electricity, and so measure it more minutely.

It is found that if a bar of bismuth and a bar of antimony be soldered together at one end, and the free ends be joined by a wire, a current of electricity will go through the wire when the solder at

FIG. 46.

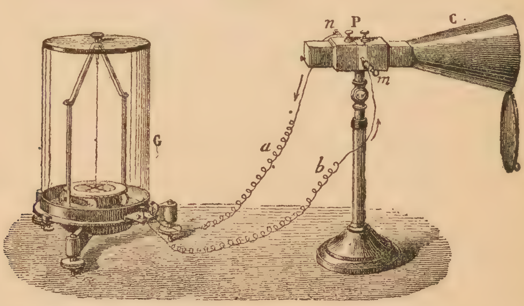
FIG. 47.



C is heated (Fig. 46). If the soldering is cooled, an opposite current results. If a number of such bars be soldered alternately (Fig. 47), the intensity of the current is increased, and a smaller degree of heat can be appreciated. Such arrangement is called a *thermopile* or *thermo-electric battery*. (See p. 318.)

Melloni's thermo-multiplier consists of this thermopile attached to

FIG. 48.



a galvanometer (Fig. 48). The thermopile is in the rectangular box. The cone C concentrates the thermal rays. G is the galvanometer, the needle of which is deflected according to the strength of the current. (See p. 262.) Boys has combined the above into one instrument called the *radio-micrometer*, suspended by a torsion fibre in the field of a strong magnet. It indicates $\frac{1}{3000000000}$° C.

What are the laws of radiation?

1. *Radiation takes place in all directions round a body.*

2. *In a homogeneous medium radiation takes place in a straight line.*

3. *Radiant heat is propagated in vacuo as well as in air.*

What are the laws of intensity of radiant heat?

1. *The intensity is proportional to the temperature of the source.*

2. *The intensity is inversely as the square of the distance.*

3. *The intensity is less the greater the obliquity of the rays with respect to the radiating surface.*

The truth of the second law follows from the geometrical principle that the area of a circle increases as the square of the radius. It will be further noticed under LIGHT.

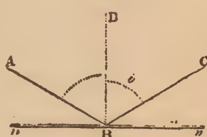
What is Prevost's theory of exchanges?

All bodies constantly radiate heat in all directions. If two neighboring bodies have different temperatures, the one with the higher will lose heat, for the rays it emits are of greater intensity than those it receives. Ultimately, the T. of both becomes the same, but heat is still exchanged, only each receives as much as it emits.

What are the laws of reflection of heat?

In Fig. 49 let *m n* be the reflecting surface, C B the *incident* ray, B A the *reflected* ray, and B D a line perpendicular to the surface called the *normal*. C B D is the *angle of incidence*, D B A the *angle of reflection*, being formed by the meeting of the incident and reflected rays with the perpendicular. The two laws, like those of light, are—

FIG. 49.



1. *The angle of incidence is equal to the angle of reflection.*

2. *Both the incident and reflected ray are in the same plane with the perpendicular to the reflecting surface.*

Reflection from concave mirrors to a definite point called the *focus* is governed by the same laws.

Heat and light laws are the same for reflection, refraction, dispersion, polarization, etc.

Describe the reflecting, absorbing, and radiating power.

The *reflecting power* of a substance is its property of throwing off a greater or less amount of incident heat. Polished silver and brass are best reflectors. Lampblack and white lead reflect none.

The *absorbing power* of a substance is its property of allowing a greater or less quantity of incident heat to pass into its mass. It is inversely as its reflecting power, yet not quite complementary. If lampblack absorbs 100 parts, metals absorb 13.

Incident heat is divided into three parts: 1st, one which is absorbed; 2d, another which is regularly reflected; and 3d, a part which is irregularly reflected, and is said to be scattered or diffused.

The *radiating power* of a body is its capability of emitting greater or less quantities of heat, and is practically identical with the absorbing power.

What is shown by the thermal analysis of sunlight?

Rock-salt allows heat of all kinds to pass, and with a lens of rock-salt the sun's rays can be concentrated upon a prism of the same substance, and a normal spectrum be obtained.

By using Melloni's thermo-multiplier we shall find that heat is dispersed as well as light. The multiplier is scarcely affected in the violet rays, but indicates a gradual rise to the red, and reaches its maximum outside the visible colors a half spectrum's length from the red. These are called extra or ultra red or Herschelian rays.

Artists, guided by an unconscious feeling, speak of blue and green as cold colors and red and orange as warm tones.

What are diathermancy and athermancy?

The power which bodies have of transmitting heat is called *diathermancy*, analogous to transparency in light.

The power of stopping radiant heat is *athermancy*, and corresponds to opacity in light.

Rock-salt, bisulphide of carbon, and dry air are quite diathermanous. Alum and sulphate of copper are quite opaque to heat.

The thickness of these substances and the nature of the source of light modify their transmitting powers.

The transmitting power of gases is different for each gas. Gases were formerly thought to be transparent to heat rays, absorbing little

or none. If the absorption by 1 in. of dry air is 1, that by 1 in. of olefiant gas is 7950, and by sulphurous acid gas is 8800.

Several vapors are still more absorptive than these gases. Aqueous vapor is one of the most energetic absorbents.

The attractions and repulsions arising from radiation are seen by means of Crookes' radiometer (see p. 21).

What are some of the applications of the above principles?

White bodies, except white lead, reflect heat very well. White clothing is best for summer, because it absorbs less heat than black.

Polished metals reflect well and emit little. The polished fire-irons are cold, while the black fender is hot. Locomotives are kept bright for æsthetic effect, and because they will thus radiate less heat. The outer surface of stoves and hot-water apparatus should be dull black, as they radiate better.

Certain bodies are used for separating heat and light in the microscope and in photography.

Rock-salt covered with lampblack or iodine transmits heat, but completely stops light. Alum does the reverse, and a vessel of this solution or of water simply may be used to avoid the heat from an electric light.

The heat waves of the sun are of two kinds—long and short. They pass through our surrounding ocean of air, heating it but little. The long waves are absorbed, but what escapes falls on the earth and heats it. Thence it is radiated back again, but its wave-lengths have been lengthened, and are now readily absorbed by the aqueous vapor, which acts as a "blanket." If this watery vapor of the atmosphere were removed, the resulting chill from too rapid radiation would destroy all life.

Glass does not screen us from the sun's heat, but it does from any obscure or diffused heat, as that from a stove or terrestrial object. This is seen in hot-beds and green-houses. The sun's heat passes through the glass unobstructed, but the return radiations from the interior have had their wave-lengths changed and cannot pass out.

CHAPTER XII.

CALORIMETRY.

What is the object of calorimetry?

Its object is to measure the quantity of heat which a body parts with or absorbs when its T. falls or rises. These quantities of heat are best expressed by their power to raise the T. of a known quantity of water.

What is the thermal unit?

There are, unfortunately, three. In France it is the quantity of heat necessary to raise the T. of 1 kilo of water through 1° C. This amount is called a *calorie.* In England and America the thermal unit is the heat necessary to raise 1 lb. av. of water. through 1° F. Ganot combines these, and takes as a unit the amount necessary to raise 1 lb. av. of water through 1° C. A *small calorie* or *therm* is the heat required to raise 1 gm. of water 1° between 0° and 4° C.

Define specific heat.

The specific heat of a body is the ratio of its *capacity for heat* to that of an equal weight of water. It is also the heat required for raising the T. of a substance a given number of degrees.

Specific heat raises T. Latent heat changes state. When equal weights of two different substances at the same T. are placed in similar vessels, and are subjected for the same length of time to the same degree of heat, their resulting T. will be unequal. Hg will be hotter than water. Both have received the same amount of heat; so it seems that the heat which raises the T. of Hg through a certain number of degrees will raise the T. of water through a less number of degrees. In other words, it requires more heat to raise the T. of water through 1° than it does to raise the T. of Hg to the same extent.

If equal weights of Hg, alcohol, and water receive the same amount of heat, the Hg will rise to 29°, the alcohol to 2°, while the water is rising 1°.

Since heat affects the T. of water *less* than that of Hg or alcohol, water is said to have a greater *capacity for heat*—takes up more without showing it.

Conversely, if the same quantity of water and Hg at 100° should be cooled down to the same point, the water will require a longer time, and will give out more heat than the Hg.

If a pound of water at 100° be mixed with a pound of Hg at 40°, the T. of the mixture will be about 98°. That is, while the water has cooled through 2°, the T. of Hg has been raised 58°.

$2:58 = 1:29$. Water has 29 times the capacity for heat that Hg has, and is again taken as a standard. When we say the specific heat of lead is 0.0314, it means that the quantity of heat which would raise the T. of a given weight of lead through 1° C. would raise the T. of the same weight of water through only 0.0314° C.

What is the cause of the differences in specific heat?

Of the whole heat applied to a liquid or solid, only a part goes to increase its T. The remainder performs *internal* and *external work* —*i. e.* overcomes cohesion and forces the molecules to take new positions, and expands against outside resistance. If we could exclude these two factors, we should have left the *true heat of temperature* or the *true specific heat.*

The greater the portion of heat consumed in interior work, the less there is left to raise its T., and consequently the greater is its capacity for heat.

In the case of water and Hg more internal work is done on the water, so its T. is not raised as high as that of Hg.

What are the methods for determining specific heats?

1. Method of melting ice;
2. Method of mixtures;
3. Method of cooling.

The *melting-ice method* is based on the fact that it requires 80 thermal units to melt 1 lb. of ice (exactly 80.025). The substance to be tested is heated to a known T. and placed in a cavity in a block of ice and covered with ice. After some time the body cools to the ice T.—viz. 0°. Now find the number of thermal units absorbed by the ice (80 times the number of lb. melted), and divide this

number by the number of degrees of heat lost by the cooling body. Sp. heat$=\frac{80\ P}{m\ t}$. P is the number of lb. of melted ice, m is the weight of the body, and t its temperature. We will find that 7 lb. of iron at 100° C. will melt only 1 lb. of ice. The heat given out by the iron was 700°, not 700 thermal units; only water would give that, each unit corresponding to a degree. The heat given out and the heat absorbed are equal.

If 700 heat degrees of iron equal 80 units of the standard, 1 iron unit equals 0.11 of a water unit—*i. e.* the heat which raises iron 1° raises water 0.11°.

$$\text{Sp. heat of iron} = \frac{80 \times 1}{7 \times 100} = \frac{80}{700} = 0.11.$$

Method by Mixtures.—A known weight of the substance is heated to a certain T., and then immersed in water whose quantity and T. are known. From the T. of the water after mixing the specific heat is determined. A lb. of water at 100° and a lb. of olive oil at 40° give a mixture at 80°.

The water has lost 20° while the oil has gained 40°. The same quantity of heat that raises water through 20° will raise olive oil through 40°; hence to raise the oil 1° requires $\frac{20}{40}$, or 0.5 as much heat as to raise water 1°. The specific heat of olive oil is 0.5.

The *cooling method* is based on the fact that bodies of different specific heats will occupy different lengths of time in cooling through the same number of degrees. Those that have the greatest sp. heat will take longest to cool.

The times, therefore, which equal weights of different bodies require for cooling through the same range of T. are directly as their specific heats.

What is the specific heat of certain bodies?

Sp. heat of	olive oil	is	0.5.
"	alcohol	"	.615.
"	ether	"	.156.
"	iron	"	.11.
"	silver	"	.051.
"	hydrogen	"	3.409.

All except H have less specific heat than water, and are expressed in fractions. Specific heat is found to increase with T., and is greater as bodies near their fusing-point.

The specific heat of a substance in a liquid state is greater than that in a solid or gaseous state—*e. g.* sp. heat of ice is .504, of water 1, and of steam .4805. The reason is that more internal work has to be done in liquids: the external work is also greater here.

What are the laws of specific heat?

(1) *Each substance has its own sp. heat.* (2) *Sp. heat increases with T.* (3) *Is greatest in liquids.* (4) *Dulong and Petit's law.* It was discovered that the product of the specific heat of any solid element into its atomic weight is approximately a constant, *viz.* 6.4. A regular inverse ratio exists between the two. Substances with low atomic weight have high specific heat, and *vice versâ.* The law may be thus stated: *The same quantity of heat is needed to heat an atom of all simple substances to the same extent.*

	Sp. heat.		At. wt.		At. heat.
Al	0.2143	×	27.4	=	5.87
P	0.1740	×	31.	=	5.39
S	0.178	×	32.	=	5.70
Zn	0.095	×	65.2	=	6.23

The figures in this last column should all be the same, and are called the *atomic heat*, but they may vary between 5.39 and 6.87. That depends, probably, on the impurity of the elements and on errors in determining their sp. heats and atomic weights. The atomic heat when divided by the sp. heat gives the at. wt. of a body, and this is one of the means of finding at. wt.

The above law explains why Hg has small sp. heat, and H large sp. heat. Hg has large atoms and large at. wt., while H has small atoms and small at. wt. The same amount of heat for every atom, but these atoms in an ounce or grain vary in number; H would have the more. (It is molecules, and not atoms, which have the same size.—*Avogadro.*)

Water is the great regulator of temperature and climate, having high sp. heat. It is a reservoir of heat, absorbing it in summer and giving it out in winter. A lb. of water in cooling from 100° to 0° C.

gives out as much heat as a lb. of red-hot iron would in cooling from 900° to 0° C.

Gases have two specific heats, one at *constant pressure* and one at *constant volume;* the former is the greater.

Problems.

When studying the latent heat of fusion and vaporization, we learned that water at 0° = ice at 0° + latent heat of fluidity, and steam at 100° = water at 100° + latent heat of vaporization.

(1) In mixing 1 lb. of water at 0° and 1 lb. of glycerin at 56.3°, the T. of the mixture will be 20°. What is the sp. heat of glycerin? *Sol.* The water gained 20° and the glycerin lost 36.3°. The same quantity of heat that raises water 20° will raise glycerin 36.3°; hence to raise glycerin 1° requires $\frac{20}{36.3}$ = .5509, as much heat as to raise water 1°. Sp. heat of glycerin = .55. Ans.

(2) The latent heat of water is 79° C. What T. would 3 lb. of water at 90° C. have after the addition of 1 lb. of ice at 0°? *Sol.* The 3 lb. contain (3 × 90) 270 thermal units. The 1 lb. of ice in becoming 1 lb. of water takes away 79 units, leaving 191. So now we are to mix 3 lb. water containing 191 units,

with	1 lb.	"	"	0 "
	4 lb.	"	"	191 units.

The mixture therefore has a T. of (191 ÷ 4) 47.75° C.

(3) What would be the T. of 10 lb. water at 0° C. after receiving 1 lb. of steam at 100° C.? The latent heat of steam is 536° C. *Sol.* 1 lb. of steam at 100° gives up 536 units in becoming 1 lb. water at 100°, and that water would also contain 100 units of sensible heat. So we mix 1 lb. water, yielding 636 units (536 + 100),

with	10 lb.	"	"	0 "
	11 lb.	"	"	636 units.

The mixture therefore has a T. of (636 ÷ 11) 57.81° C.

(4) How much heat is required (thermal units) to raise ice from 0° F. to steam at 300° F.? *Sol.* Ice or steam in rising a certain number of degrees would not absorb a thermal unit for a degree, as water would, for their specific heats are less than unity. So we must know the sp. heats of ice, water, and steam, and the latent heats for water and steam.

Sp. heat of ice is 0.504.
" water is 1.
" steam is 0.4805.
Latent heat of water is 142.2° F. (79° C.).
" steam is 964.8° F. (536° C.).

Ice in passing from 0° F. to its melting-point would not absorb 32 units, but $32 \times .504 = 16.128$ units. Water in passing from 32° to 212° would absorb $180 \times 1 = 180$ units. Steam in passing from 212° to 300° F. would absorb $(300 - 212)\ 88 \times .4805 = 42.284$ units.

To raise ice from 0° to 32° requires	16.128	units.
To melt ice at 32° "	142.2	"
To raise water from 32° to 212° requires	180.	"
To convert water at 212° into steam at 212° requires .	964.8	"
To raise steam from 212° to 300° requires	42.284	"
Sum-total	1345.412	units.

Ans.

CHAPTER XIII.

STEAM-ENGINES.—SOURCES OF HEAT AND COLD.—MECHANICAL EQUIVALENT OF HEAT.

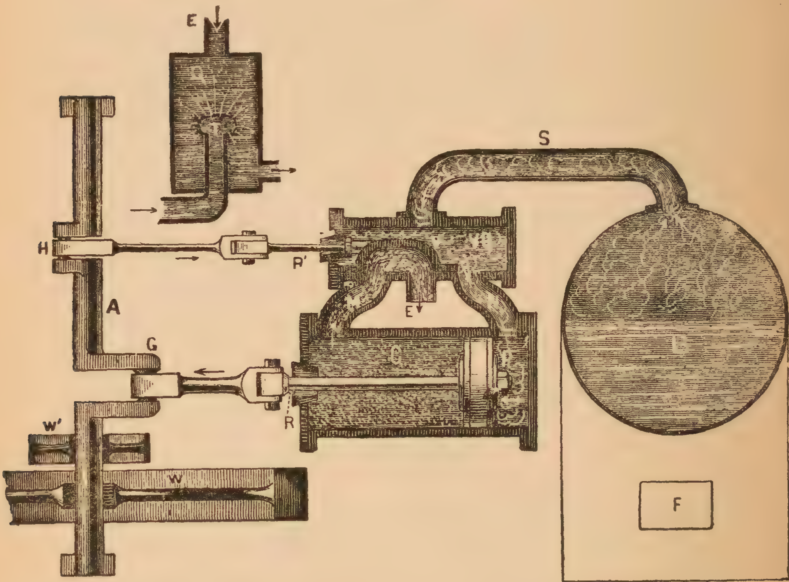
Describe the essential features of steam-engines.

Steam-engines are machines in which the alternate expansion and condensation of steam imparts a rectilinear motion to a piston, and this is changed into circular motion by various mechanical arrangements. In Fig. 50, B represents the *boiler*, S the *steam-pipe* passing to V C, the *valve chest*. The *slide-valve* V is moved to and fro by the *eccentric rod* R′, and this admits steam alternately on each side of *piston* P. Either M or N is always open, and as steam enters *cylinder* C by N it pushes P in the direction of the arrow, while steam on the other side escapes by *exhaust-pipe* E. Finally, N is closed and M is opened, the valve and piston moving in opposite directions.

This variety is known as the double action or Watt's steam-engine.

One variety of boiler is the *Cornish*, crossed by a series of vertical *Galloway* tubes which circulate water, the hot gases passing through one large tube. But in marine and locomotive boilers small horizontal tubes are used to convey the hot gases, and they are surrounded by water.

FIG. 50.



In the *single-acting* or *Cornish* engine the cylinder is vertical, and steam acts only on one face of the piston, a counterpoise pulling it back. These are of but little use, but may pump water from mines or supply water to towns.

Other parts of an engine are the *pressure-gauge*, *water-gauge*, *safety-valve*, and in the horizontal stationary engine the *governor*, which controls the admission of steam to the cylinder and gives the engine automatic power over its own speed.

Locomotives are simply steam-engines mounted on a carriage, which propel themselves by transmitting motion to their own wheels.

Steam-pressure is commonly higher here than in other engines, 120 or 130 lb. to the sq. in. Marine engines use 70 to 80 lb., and stationary ones still less.

The three great types are, then, the Cornish engine, the ordinary horizontal engine, and the locomotive engine. There are also *condensing* and *non-condensing* engines.

After the steam has done its work in the cylinder, it may be conducted through the exhaust-pipe to chamber Q (Fig. 50), where by means of a spray of cold water it is suddenly condensed. If the exhaust-pipe communicates with the outside air, as in *non-condensing* engines, there is an atmospheric resistance of 15 lb. to each sq. in. of the piston's surface. So condensing engines are more economical, and are usually *low pressure.* Locomotives have no condenser and are high pressure. *Compound condensing* engines receive the steam at high pressure in one cylinder. Used here, it still possesses some tension, and is transferred to a second larger cylinder before being sent to the condenser. The first cylinder is thus never exposed to the condenser temperature, a saving in heat. This type is universal for marine purposes.

The rates of work of engines are compared by means of the *horse-power* — 550 foot-pounds per second or 33,000 foot-pounds per minute.

The horse-power used abroad, of 75 kilogrammetres per second, equals 542 foot-pounds, 2% smaller than ours. The propulsion of some vessels requires 5000 or 6000 horse-power.

The steam-engine, with all its improvements, is exceedingly wasteful. The best only utilizes 20% of the heat-power.

Hot-air and *gas-engines* succeed on a small scale. In the latter the expansive force of coal gas, mixed with air and ignited by an electric spark, moves the piston.

Sources of Heat and Cold.

What are the sources of heat?

1. Mechanical sources:
    - Friction;
    - Pressure;
    - Percussion.

2. Physical sources:
   - Sun;
   - Earth;
   - Molecular actions;
   - Change of state;
   - Electricity.
3. Chemical sources:
   - Molecular combinations as combustions;
   - Animal and vegetable heat.

Discuss the mechanical sources.

Friction of two bodies produces heat, depending on the amount of pressure and rapidity of motion. This is seen in the axles of carriage- or car-wheels, the "hot box" being a familiar example. There are anti-friction metals, as Babbitt's metal. It costs the Erie Railroad $1000 per day for lubricators. Two pieces of ice in a vacuum below zero can be partly melted by friction. The T. of water can be raised by shaking it. The luminosity of shooting stars is thought to be due to their friction against the air. Their velocity may be 150 miles per second.

If a body is *compressed*, so that its density is increased, its T. rises. When heavy weights are placed on metallic pillars, heat is evolved. The stretching of a metallic wire causes a diminution of T. Heat-production by compressed gases is seen in the *pneumatic syringe.* This is a closed, thick-walled glass tube with a tightly-fitting piston. A bit of cotton moistened with ether is placed at the bottom, and, the tube being full of air, the piston is suddenly plunged downward. The compressed air disengages enough heat to ignite the cotton—a T. of about 300° C. The fire-syringe with tinder at the bottom was useful before the days of matches. The powder-ram for pile-driving is another application. The powder on top of the pile is exploded by the compressed air in front of the falling rammer, and this explosion reacts in two directions: one force sends the rammer to its former position, and the other urges on the pile with greater power than the weight of the rammer could do alone.

Percussion is also a source of heat. A piece of iron hammered on

an anvil becomes hot, due to increased molecular motion, and not to increase of density. A pound ball with a velocity of 1600 ft. per sec. will produce upon the target 28.7 thermal units, enough to melt the lead. The amount of heat depends upon the momentum, velocity $\times$ mass.

Mayer has calculated that if the motion of the earth were suddenly arrested, the T. produced would be sufficient to melt and volatilize it to the depth of 800 miles.

What are the physical sources of heat?

Solar Radiation.—It is calculated that if the total quantity of heat which the earth receives from the sun in one year were employed to melt ice, it would melt a layer all around the earth of 35 yards thickness; and yet this quantity which the earth receives is only $\frac{1}{2381000000}$ of the total heat emitted by the sun.

Simple combustion is not sufficient to account for the sun's heat. Even if the sun consisted of H, which of all substances would yield the most heat, combining with O, the heat thus produced would last only about 3000 years, and combustion can occur only once.

Others say the heat is kept up by the fall of aërolites against its surface. This must be a very small factor, or it would increase the mass of the sun, and so alter the velocity of the planets. The best theory is that of *condensation*. Heat is set free by a shrinkage of its mass. A contraction of only $\frac{1}{10000}$ would be sufficient to produce the present heat of the sun for 2000 years.

Terrestrial Heat.—Our globe possesses a heat peculiar to itself. The variations of T. on its surface penetrate to a certain depth, when is reached the layer of *constant temperature.* At Paris this layer is at a depth of 30 yds., and the T. is constant at 11.8° C. Below this layer the T. increases about 1° C. for every 90 feet. According to this, at a depth of two miles we should reach a T. of 100° C., and at 40 miles the T. would be sufficient to melt all substances which exist on the earth's surface.

There are various hypotheses to account for this internal heat. The theory of an internal molten mass best explains the phenomena of earthquakes, volcanoes, hot springs, and this internal heat. The earth may have cooled faster than the sun, as it is smaller. Yet many geologists are still in doubt.

Molecular actions, such as absorption, imbibition, or capillarity, produce heat.

When a porous substance absorbs a liquid or a gas, heat is generated. 1 cu. in. of fresh charcoal will absorb 90 cu. in. of ammoniacal gas. Perhaps some of the gas is liquefied in the pores and gives off its latent heat.

Spongy platinum in O and H gases gets red hot. An apparatus called *Döbereiner's lamp* depends on this property, where a jet of H is ignited when blown across the Pt. Gas condensed into water produces heat. Moist membranes will rise in T. from absorption.

Change of state produces cold or absorbs heat, and has been discussed.

Electricity is another source. In the electric light itself the carbon is heated to 2000° C. or 3000° C.

No metal can resist the heat of an electric spark. A stroke of lightning on the seashore melts the sand, forming "fulgurites." It is the poor conductor which becomes heated.

Describe the chemical sources of heat.

Heat is molecular motion, and heat and motion are always mutually convertible. If a chemical combination takes place slowly, as when iron oxidizes in air, the resulting heat is imperceptible, but just as much in quantity as if the combination were rapid and the heat intense. *Combustion* is chemical combination, and Ganot says it is attended with evolution of light and heat.

O is most often one of the combining elements, but Sb or P will burn in Cl gas.

Combustion cannot be distinguished by the amount of heat evolved. We live in a combustion at 37° C., and yet it is combustion at 1000°.

The waste products are generally CO_2 and H_2O.

$$C \text{ in } \left\{\begin{array}{l}\text{anthracite}\\ \text{charcoal}\\ \text{coke}\end{array}\right\} \text{burns to } CO_2.$$

$$C_xH_x \text{ in } \left\{\begin{array}{l}\text{marsh gas}\\ \text{kerosene oil}\\ \text{bituminous coal}\\ \text{vegetable tissue}\end{array}\right\} \text{burns to } CO_2 \text{ and } H_2O.$$

The *quantity* of heat is due to the amount of matter involved, but the T. depends upon the *rapidity* of the process.

Pt can be melted with a blowpipe and a candle, and yet not in a forge.

1 lb. of iron	burned in O_2 produces	1,576	heat units.
1 lb. of charcoal	" "	8,080	"
1 lb. of hydrogen	" "	34,462	"

These figures are about in proportion to the O_2 required to burn them. It is a fixed and definite matter. Nearly all the heat of earth comes from the sun, and is locked up in various substances. As we burn coal in the grate, we may imagine we are basking in the sunlight of prehistoric ages. The vegetation of those ages absorbed sunlight and heat, became coal, and now gives back what it received.

What is the principle of Davy's lamp?

Davy, in inventing a safety-lamp for miners, found that when two vessels filled with explosive gases are connected by a narrow tube and the contents of one fired, the flame is not communicated to the other. The flame is extinguished by cooling, provided the length, diameter, and conduction of the tube bear a certain proportion to each other.

The safety-lamp is an ordinary oil lamp with its flame enclosed in a cage of wire gauze having about 400 apertures to the square inch. Fire-damp (CH_4) mixed with air has a very high kindling-point, and the wire gauze may be looked upon as a series of very short square tubes which completely arrest the passage of flame into the explosive mixture. Although the CH_4 may burn inside the cage, the mass outside is not ignited.

Animal heat is also a result of combustion. We take in compounds rich in O_2, like starch and sugar, and ready to undergo new combinations and to give off the used-up substances CO_2 and H_2O. The plants here come in and take up these two products, and recombine them into starch, sugar, wood, etc. The plant and the animal thus work in a circle.

The plant requires heat to do this work, and gets it from the sun, which reappears during combustion—*i. e.* during animal digestion or during the burning of wood or coal.

Vegetable heat is hardly possible, as the process of vegetation is not an oxidation. Some plants at the time of blossoming do have an increase of T.

Mention the different methods of heating.

Open fire, enclosed fire, hot air, steam, and hot water.

What are the sources of cold?

(1) Change of state;
(2) Expansion of gases;
(3) Radiation.

(1) The withdrawal of latent heat produces change of state, and results in cold of a greater or less degree.

(2) In the expansion of gases heat is necessary for the increase in volume and for the greater molecular activity, and it is obtained from elsewhere, producing cold. The fog in the neck of an open beer-bottle is due to the chill of an expanding gas. When a gas is compressed, heat is produced; when it is rarefied, a lowering of T. follows.

Refrigerating machines depend on the principle of first compressing the gas or air, producing heat, and next on the expansion of the same, producing cold. Windhausen's machine, run by a steam-engine, can cool in an hour 15,000 to 150,000 cu. ft. of air through 40° or 100°. Some such machine is used in breweries, oil-refineries, large meat-rooms, and for the production of ice.

(3) *Radiation*, especially nocturnal, produces cold in nature. During the day the earth receives more heat than it can radiate, and its T. rises; the reverse takes place at night. If clouds are present, they themselves have a certain degree of T., which they radiate toward the earth, and so on a cloudy night the dew is less, as terrestrial objects cannot cool sufficiently to bring their neighboring layers of air to saturation. A clear night increases dew, or a feeble breeze, as it renews the air. A strong wind will diminish it, as it does not allow the air time to cool by contact. The blade of grass radiates well, and quickly cools the adjacent layer of air to its dew-point. Polished metals radiate but little, and so generally have no dew deposit.

Discuss the mechanical equivalent of heat.

A definite quantity of mechanical work can always produce a definite quantity of heat; and, conversely, this heat, if completely converted, can perform the original quantity of work. The branch of science which treats of this relation is called *thermo-dynamics.*

When a projectile strikes a target, motion is not destroyed. Mass motion becomes molecular motion, and that is heat. Count Rumford was among the first to suspect the relation between heat and work. He noticed that water would boil if introduced into a cannon while being bored. He obtained certain figures, which were corrected by Joule of England in this manner: A copper vessel was filled with water or Hg, and its enclosed paddle-wheel made to rotate by two falling weights. After several descents of the weights, the number of heat units gained by the water from the friction of the wheels against its molecules could be determined, and also the amount of work done by the weights expressed in foot-pounds. He found that the heat which will raise 1 lb. of water 1° F. will lift 772 lb. 1 ft. high, or a pound weight in falling 772 ft. will produce heat enough to raise 1 lb. of water 1° F. This figure is called the *mechanical equivalent of heat*, or *Joule's equivalent.*

According to Ganot's system, 1 thermal unit = 1389.6 ft.-lb.
" " French " 1 " " = 424 kilogrammetres.

The quantity of heat which will raise 1 kilo of water from 0° to 1° C. will raise a 424 kilo-weight (exactly 426.4) 1 metre high. 480 tons of coal placed under an engine would have raised the Great Pyramid of Egypt, which took 100,000 men twenty years to build. This pyramid is 700 ft. square at its base and 500 ft. high.

What is meant by correlation and conservation of energy?

These two doctrines are the corner-stones of modern science: (1) All kinds of energy are so related to each other that energy of any kind can be changed into energy of any other kind. This is the doctrine of *correlation* or *transference of energy.*

(2) When one form of energy disappears, an exact equivalent of another form always takes its place, so that the sum-total of energy is unchanged. This is known as the doctrine of *conservation of energy.* There are similar laws for matter.

What may be the result of dissipation of energy?

Following out the idea of dissipation of energy, we may come to a rather startling conclusion. As far as we can understand the present condition of the universe, there is a tendency for all energy to become heat, and for all heat to become so diffused by conduction and radiation that all matter will have the same temperature. All the energy of the universe will become unavailable, and all motion and change of every kind will cease.

BOOK III.

ON LIGHT.

CHAPTER XIV.

TRANSMISSION, VELOCITY, AND INTENSITY OF LIGHT.

What is light and its theories?

Light is the agent which by its action on the retina excites in us the sensation of vision. It is known only by its effects. That part of physics which deals with the properties of light is called *optics.* Heat, light, and electricity were called the "imponderable fluids," and such an idea necessitated a certain theory (emission) to explain their propagation.

As for heat, there are also two theories in regard to the origin and transmission of light:

1. The emission, or corpuscular theory;
2. The undulatory, or vibration theory.

According to the first view, we have to believe that there is a translation of particles of light, with almost infinite velocity, which penetrate the eye and act upon the retina. Newton supported this view.

According to the *undulatory theory*, the luminosity of a body is due to the infinitely rapid vibration of its molecules, which is communicated to the medium called *luminiferous* ether, and thus is propagated in the form of waves to the retina. This theory is sufficient, yet a difficulty is met when we try to consider what this ether really is. It must be thin and tenuous, intermolecular, uninfluenced by gravitation, yet thick and dense—dense enough to hin-

der the motion of small comets. Lodge says that "of + and − electricity we imagine ether to be composed. It consists of electricity in a state of entanglement similar to that of water in jelly." The waves are made up of condensations and rarefactions, the vibrations taking place in a plane at right angles to the direction of the wave, just as, when we consider any one particle of a vibrating rope, we see this spot move up and down or laterally, but not onward. This undulatory theory resulted from the study of sound, where air is the medium of propagation.

What are luminous bodies?

Luminous bodies are those which emit light. Illuminated bodies are those which receive light from luminous ones. A body rendered capable of emitting light by being heated is called *incandescent.* Our ordinary lights are due to particles of incandescent carbon, and the flame "smokes" when all the carbon is not burned.

As a substance becomes hotter and hotter its color changes.

A solid beginning to give light at 1000° F. is red hot.
" " " 2000° F. is white hot.
" " " 3000° F. is violet hot.

Waves of different lengths cause the colors.

The length of violet waves is $\frac{1}{65000}$ in.—shortest.
The length of red waves is $\frac{1}{33000}$ in.—longest.

Heat all these colors to a certain degree, and we get white. A lower T. gives red, and a higher one violet.

What are transparent, translucent, and opaque bodies?

Transparent, or *diaphanous*, bodies readily transmit light, and objects can be distinguished through them.

Translucent bodies transmit light imperfectly. Objects cannot be distinguished through them.

Opaque bodies do not transmit light. None are quite opaque: if cut into sufficiently thin leaves, all are translucent.

What is a luminous ray and pencil?

A *ray* is a mere line or direction that light takes. It has no dimension except length, and is a conception of the mind.

A *pencil of light* is a bundle of rays, and has three dimensions.

There are three kinds: *parallel*, or a *beam* of parallel rays; *divergent*, when the rays separate; and *convergent*, when they tend toward the same point.

Every luminous body emits divergent rectilinear rays from all points and in all directions. Convergent rays are only produced artificially.

Light itself is invisible. You can only trace the path of a sunbeam by the floating particles of dust. If the eye is placed in its path, you become aware of its presence, not by seeing the light, but by seeing the object which sends the light.

How is light propagated in a homogeneous medium?

Any space or substance through which rays can pass is a medium. It may be a vacuum. A medium is said to be *homogeneous* when its chemical composition and density are the same in all its parts.

In every homogeneous medium light is propagated in a straight line. Every gunner recognizes this fact in taking aim.

When light reaches a body which it cannot penetrate, it is *reflected.* When it passes from one medium to another, it is bent or *refracted.*

What are shadow and penumbra?

When light falls upon an opaque body, it cannot penetrate into the space immediately behind it, and this space is called the shadow. There cannot be a proper geometrical shadow, as light never comes

FIG. 51.

from an exact point. There is also a bending around of the light behind the opaque body, known as *diffraction.*

Physical shadows are those which are really seen, and are never sharply defined.

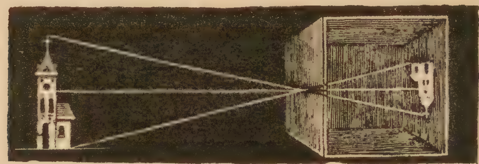
The penumbra is a faint shadow around the central darker shadow. In Fig. 51 suppose S L is the luminous sphere, and M N

the illuminated one. If A G be moved as a tangent to both spheres, it will describe a cone, tracing a perfectly dark space, M G H N. This is the true shadow. If we move a second straight line L D as tangent to both spheres, it will describe a new conical surface, B D C. This space *a b* between the two conical surfaces is neither quite dark nor quite light, receiving light from some parts of the luminous body, and not from others. It is the penumbra (almost a shadow). The explanation of the phenomena of *eclipses* and *transits* of Venus or Mercury over the sun follows from the theory of shadows.

Describe the camera obscura.

The camera obscura, or "dark chamber," was invented by Porta, a physician of Naples, over three hundred years ago. It is simply a box with a small aperture in one side, and the side opposite acts as a screen for the reception of images of outside objects. These images are inverted (Fig. 52), and their shape is that of the external

FIG. 52.



object and independent of the shape of the aperture. That the shape of the image has nothing to do with the shape of the aperture is seen among the shadows of foliage. The image of the sun is always round or elliptical, according as the ground is perpendicular or oblique to the sun's rays. The aperture of the camera must be so small, however, that no two points of the object shall cast their image on the same point of the screen. The size of the hole also determines the amount of light entering the box. A small one gives a more distinct image, but at the expense of less light.

The reason that the image is inverted is that the rays, continuing in straight lines, cross each other at the aperture. The rays from the spire (Fig. 52) reach the screen at a low point, while those from the base of the church come to higher parts. The brightness and

precision of these images are increased by means of lenses placed at or near the aperture.

Then we have a photographer's camera.

What is the velocity of light?

The velocity of light was first determined by Romer of Denmark in 1675, from observations upon the eclipses of one of Jupiter's moons. This first satellite (E, Fig. 53) passes into Jupiter's shadow

FIG. 53.

at equal intervals of time every 42 hours and some minutes. While the earth is in the part of its orbit *a b*, the intervals between the successive eclipses of E do not materially differ. But as the earth moves away in its revolution around the sun toward T′, the interval between the eclipses increases, and at T′ there is a retardation of 16 m. 26.6 sec. between the time at which the phenomenon is seen and that at which it is calculated to take place. At T′ the light from E has had to travel TT′ farther to reach the earth than when it was at T; *i. e.* light requires 16 m. 26.6 sec. to travel TT′, which is the diameter of the terrestrial orbit, or twice the distance of the earth from the sun. This distance is reckoned at 91,500,000 miles $\times 2 =$ 183,000,000 ms., the length of TT′. 16 m. 26.6 sec. $=$ 986.6 sec.

If light travels 183,000,000 miles in 986.6 sec., it will travel $\frac{183000000}{986.6}$ miles in 1 sec.—viz. 185,485 ms. In round numbers, we may call the velocity of light 186,000 miles per sec.

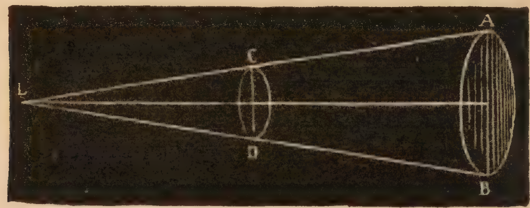
For sound to travel the distance from earth to sun and back would require 29 years; light does it in 16½ min. The latter is the velocity with which ether vibrations are transmitted; the former is the speed with which vibrations in air move. Light from the nearest stars would require 3¼ years to reach us. Some are so far away that they may have been extinguished for hundreds of years without our knowing it.

What is the law of the intensity of light?

The intensity of light on a given surface is inversely as the square of its distance from the source of light. This is the law of inverse squares. The intensity of light or heat means the quantity of light or heat per unit surface.

The law only applies to naturally divergent rays, and not to light from lenses. In Fig. 54 let the screen C D be placed at a certain distance from L, the source of light, and A B at double this distance.

Fig. 54.



The diameter of A B is twice that of C D, and the surfaces of circles are to each other as the squares of their diameters. A B has four times the area of C D—four times as large for twice the distance—or the intensity of illumination on A B is diminished fourfold by doubling its distance from L.

It would require 4 candles to give the same illumination to A B that 1 furnishes to C D.

What is the standard candle?

There is a good deal of discussion as to an established unit for comparing the intensities of light. The following is adopted from the English gas-makers: the *candle-power* is the amount of light given by a spermaceti candle burning 2 grains per minute, and of such size that 6 weigh 1 pound. In France they use the Carcel lamp, burning 42 gm. colza oil per hour; 1 *carcel* = 9.5 candles. The light from 1 sq. cm. of melted Pt is also standard = 19.75 candles.

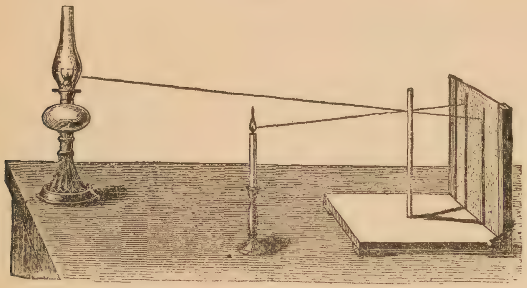
Describe the two chief kinds of photometers.

A *photometer* is an instrument for measuring the relative intensities of lights.

Rumford's is a shadow photometer. An opaque rod (Fig. 55) is

fixed in front of a ground-glass screen; then the lights to be compared project the shadows of the rod on the screen. Move the lamp till the two shadows are equal, and note how much farther

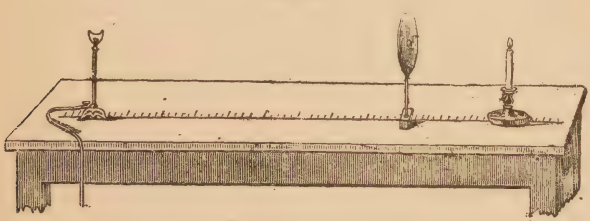
FIG. 55.



away it is than the standard candle. If twice as far, its intensity is four times as great as that of the candle.

Bunsen's photometer depends upon the following principles: It must be used in a black-walled room. A grease-spot on a piece of blotting-paper appears translucent. If illuminated from the front, it appears darker than the surrounding space: if illuminated from behind, the spot will appear light on a dark ground. When the illumination is the same on both sides, the greased part and the rest appear unchanged. Set two lights (Fig. 56) 100 in. apart, one of

FIG. 56.



which is the standard candle. Move the paper screen with its spot until there is no difference in the brightness of the greased part and the rest of the screen. Measure the distances of the lights from the screen, and their relative illuminating powers are directly as the

squares of these distances. This does not contradict the law of inverse squares, which applies when only one light is moved toward or away from a screen. A difference in strength of light or shadow can be perceived when the duller light is $\frac{59}{60}$ of the brightness of the other.

An ordinary kerosene lamp has	8–10	candle-power.
" student " "	12	"
" gas-burner in N. Y. has	18–30	"
Most powerful electric arc "	55,900	"

If the lights for comparison differ in quality, one or more definite colors from each source are compared by means of the spectroscope. One light is moved till the intensities of a certain color are the same. This instrument is the *spectro-photometer.*

CHAPTER XV.

MIRRORS AND LENSES.

Reflection of Light.—Mirrors.

What is reflection and its laws?

Reflection of light is the rebound or turning back of a luminous ray when it meets a polished surface. The laws are the same as those of heat:

(1) *The angle of incidence is equal to the angle of reflection.*

(2) *The incident and the reflected ray are both on the same plane, which is perpendicular to the reflecting surface.* (See Fig. 49.)

These laws can be proven mathematically correct by means of a ray striking upon a mirror placed in the centre of a graduated brass circle held vertically.

What are mirrors?

Mirrors are bodies with polished surfaces which show by reflection objects presented to them. The place at which the objects appear is the *image.*

Mirrors may be *plane*, *concave*, *convex*, *spherical*, *parabolic*, *conical*, etc.

Mirror-glass is cast upon an iron table, and then rubbed smooth

with sand, next with emery, and next with oxide of iron. The amalgam back is tin and Hg.

How is an image formed by a plane mirror?

In a plane mirror the image is as far behind as the object is in front. In Fig. 57 let the ray from A be reflected at B, making the

FIG 57.

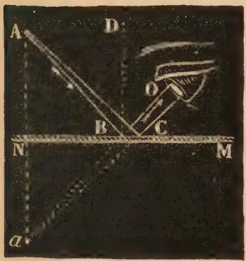
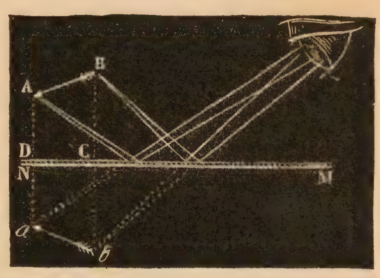


FIG. 58.



angle D B A equal to D B O. Draw A N a perpendicular to M N, and it can be proven the triangles A N B and a N B are equal; therefore the line a N = A N, and the point a is as far behind the mirror as A is in front of it. The rays from A follow the same direction as if they had proceeded from a, and the eye is thus deceived. The image of any object can be obtained by constructing according to this rule the image of each of its points. (See Fig. 58.) In plane mirrors the image is of the *same size as the object*, is *erect* and *virtual*, but suffers a *lateral inversion*. Place a printed page in front of the mirror and note the effect upon the letters—just as when two persons stand face to face, the right hand of one is opposite the left hand of the other.

What is the difference between virtual and real images?

In Fig. 57 the eye was deceived by an image that had no real existence. No luminous rays are coming from the other side of the mirror. They are imaginary, and made by the eye, and form a *virtual image.* Where the reflected rays converge in front of a mirror on the same side that the object is, they form a *real* image, and it can be caught upon a screen.

A real image is one formed by the reflected rays themselves: a vir-

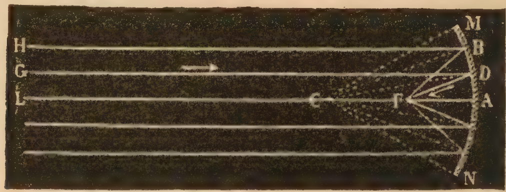
tual image is one formed by their prolongations. Many phenomena are produced by reflection from mirrors, as Pepper's ghost and the head of John the Baptist.

Curved Mirrors.

Give definitions of terms connected with spherical mirrors.

Of curved mirrors those most often used are *spherical* and *parabolic.* Spherical are those whose curvature is that of a sphere. According as the reflection takes place from its inner or outer surface, it is *concave* or *convex.* In Fig. 59 let C be the centre of a

FIG. 59.



hollow sphere of which M N forms a part. It is called the *centre of curvature.* The point A is the *vertex.* The straight line A L drawn through the vertex and centre of curvature is the *principal axis.* Any other straight line drawn through C and meeting the mirror is a *secondary axis.* The *focus* is the point at which the reflected rays meet. The distance M N is the *aperture* of the mirror.

How to find the foci in spherical concave mirrors.

A concave mirror may be considered as made up of an infinite number of small plane surfaces, and the radii of the sphere, C M or C B, are perpendicular to these surfaces.

When the rays come from an infinite distance, and are practically parallel to the principal axis, the ray G, for example, strikes the small plane surface at D, and is reflected according to the laws of reflection, making the angle of reflection F D C = to the angle of incidence G D C.

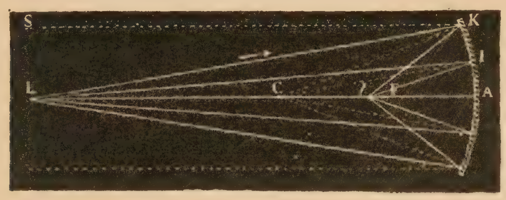
Any other reflected ray will pass very nearly through this same point F on the principal axis, which is called the *principal focus*, and the distance A F is the *principal focal* distance. F is just half-

way between the centre of curvature and the vertex. It is also the focus for parallel heat-rays as well as for luminous ones.

Conversely, if the luminous point be placed at F, the reflected rays will be parallel, as D G, B H, etc.

Suppose divergent rays are emitted from some point, L (Fig. 60). Then the angles of incidence are smaller than in the above case, and

FIG. 60.



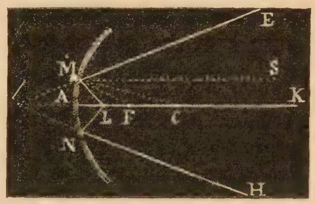
therefore the corresponding angles of reflection will be smaller, and the ray L K after reflection will meet the axis at some point *l* between C and F. All the rays from L will intersect at *l*. L and *l* are called *conjugate foci*.

A *focus* is the point where reflected rays meet. A *principal focus* is the point where parallel rays meet after reflection.

Conjugate foci are points so related that rays from either one converge at the other. They are points where other than parallel rays meet.

Suppose in Fig. 60 that L is brought near to C; then *l* approaches it in a corresponding manner. When L is at C, *l* also coincides; the incident ray is reflected on itself, and no image is formed. When L is between C and F, the conjugate focus is on the other side of C. When L coincides with F, the reflected rays are parallel to the axis, and form no focus (Fig. 59).

FIG. 61.



If L continues to approach the mirror (Fig. 61), it makes a large angle of incidence with the perpendicular C M, larger than F M C, which gives a ray parallel to the axis. All the reflected rays from L will be divergent, and neither

intersect nor be parallel. But if they are conceived as prolonged behind the mirror, they will intersect at l. This is a *virtual focus.*

It will be noticed that the position of the principal focus F is constant, while that of virtual and conjugate foci varies. The principal and conjugate foci are real, always on the same side of the mirror as the luminous point, while the virtual focus is on the other side.

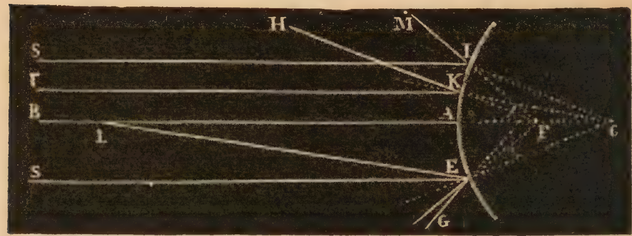
If L be on a secondary axis instead of a primary, focus l will also be on this axis, and be principal, conjugate, or virtual.

The radius of curvature of a mirror is twice the focal distance; the focus can be found by means of reflected sun's rays.

How to find foci in convex mirrors.

In convex mirrors the foci are all virtual (Fig. 62). Rays parallel

FIG. 62



to the axis are divergent on reflection, and when continued meet at a focus behind the mirror, which is the *principal virtual focus.*

What is the general effect of concave and convex mirrors?

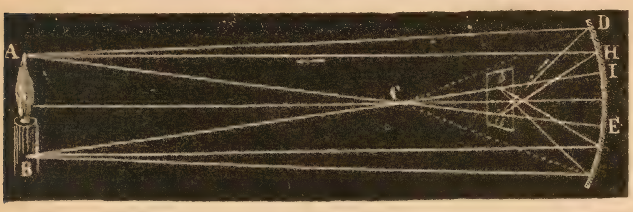
The general effect of a concave mirror is to collect rays, increasing convergence or decreasing the divergence of incident rays. A convex mirror scatters rays.

How are images formed in concave mirrors?

Take for an object A B in Fig. 63. To find where an image will be, always proceed thus: first draw the primary axis. Next draw secondary axes, as A E and B I. Place F halfway between C and the mirror. Then draw radii from C to any point where an incident ray may strike, as C D. Make the angles of incidence and reflection equal. Ray A D is continued after reflection across the principal axis, and A H through the principal focus, to some point a on the secondary axis A E.

The image of B also falls on secondary axis B I at *b*: *b* and *a* are conjugate foci of B and A. The images of all the points of the

Fig. 63.



object will fall between *a* and *b*, being between and limited by the secondary axes.

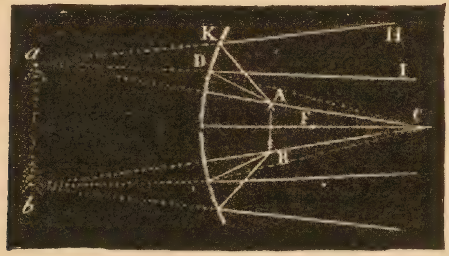
The image is *real*, *inverted*, *smaller* than the object, and placed *between the centre of curvature and the principal focus.*

An object at C produces no image. One between C and F, as at *a b*, produces the image A B, real, inverted, and larger than the object.

The image gets larger as the object approaches the focus. An object at the focus produces no image, for the reflected rays are parallel to the secondary axes, forming no conjugate foci.

When the object is between F and the mirror: Draw secondary axes and radii as before (Fig. 64). The reflected rays diverge and form

Fig. 64.

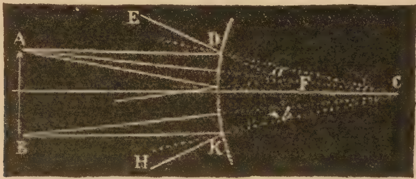


an image behind the mirror, between the prolongations of the secondary axes. This image is *virtual*, *erect*, and *larger* than the object.

How are images formed with convex mirrors?

All the incident rays are divergent after reflection, and only their prolongations form an image behind the mirror (Fig. 65). Hence,

FIG. 65.



whatever the position of an object in front of a convex mirror, the image *is always virtual*, *erect*, *and smaller* than the object.

Summary of images formed by mirrors.

Plane Mirrors.—The image is *virtual*, *erect*, and of the *same size* as the object. It suffers *lateral inversion*, and is as far behind the mirror as the object is in front of it.

Concave Mirrors.—They make both real and virtual images. (1) If the object is at such a distance that its rays are parallel, the image is *real*, *inverted*, *smaller* than the object, and at the principal focus. (2) If the object is beyond C, the image is *real*, *inverted*, *smaller* than the object, and between C and F. (3) If the object is at C, the image is reflected back upon it. (4) If the object is between C and F, the image is *real*, *inverted*, *larger* than the object, and beyond C. (5) If the object is at F, no image is formed. (6) If the object is between F and the mirror, the image is *virtual*, *erect*, and *larger* than the object.

Convex Mirrors.—The image is *always virtual*, *erect*, *and smaller* than the object.

Cylindrical and conical mirrors ludicrously distort objects. Spherical mirrors make them appear smaller or larger, but they are still symmetrical.

What is the effect of parabolic mirrors?

Parabolic mirrors exactly focus to one point all parallel incident rays. Spherical mirrors do not do this exactly. A luminous point at the focus of a parabolic mirror therefore sends out parallel rays.

They are used behind the head-lights of locomotives, and formerly in lighthouses. The echelon lens (step of a ladder) is now used in lighthouses.

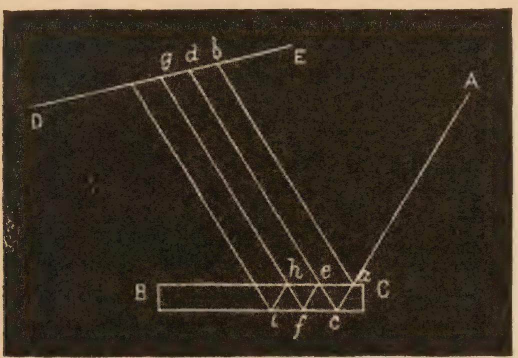
What is spherical aberration by reflection?

When the aperture of a spherical mirror does not exceed 8° or 10°, the reflected rays pass through a single point. With a larger aperture the rays reflected near its edges meet the principal axis at a point nearer the mirror than the others do. Hence arises a lack of precision in the images, called *spherical aberration by reflection.* Every reflected ray cuts the one next to it, and their points of intersection form a curved surface, called the *caustic by reflection.* This curve can be seen when light is reflected from the inside of a cup containing milk.

Explain the formation of multiple images by glass mirrors.

Metallic mirrors and polished surfaces only give one image. Glass mirrors have two reflecting surfaces. When the image of a candle-flame is looked at obliquely before a looking-glass, the first image is feeble, coming from the anterior surface; a second is distinct and bright, and comes from the quicksilver on the back. This image is distant from the first by double the thickness of the glass. In Fig.

FIG. 66.



66 let the ray A a strike the mirror B C obliquely. A portion of the ray is reflected to b, but another enters the glass a c, and is re-

flected from the amalgam, striking at *e*. Only a part of this goes out in the line *e d;* the rest is reflected back again to the posterior surface, and so on until the original ray undergoes so many splittings that it can no longer produce distinct effects. If an eye were placed at *b*, *d*, *g*, it would see multiple images of A in the directions of *b a*, *d e*, etc.

How are multiple images formed by two plane mirrors?

Multiple images are formed when the object is between two plane mirrors. The images are reflected from one to the other. If the mirrors are at an angle of 90°, three images are seen, 60° produces five, and 45° seven images. When the mirrors are parallel an infinite number of images results.

The kaleidoscope depends upon this property. Three mirrors are placed inside a tube and inclined at angles of 60°. These enclose bits of colored glass, producing an endless variety of shapes.

What is diffused light?

Light falling upon an opaque body separates into three parts: one is *reflected regularly;* another *irregularly—i. e.* in all directions; and a third is *absorbed.* The irregularly reflected light is called *scattered* or *diffused* light, and it is this which makes bodies visible. A rough surface is made up of planes turned in every direction; hence the rays are reflected in every direction.

Regularly reflected light does not give us images of the reflecting surface, but of the body from which the light proceeds.

Perfectly smooth polished surfaces would be invisible, reflecting every ray and diffusing none.

The intensity of reflected light increases with the degree of polish and the obliquity of the ray. Out of 1000 parts of light which strike water perpendicularly, only 18 are reflected. If the angle of incidence is 89½°, 721 parts are reflected.

What are some of the applications of mirrors?

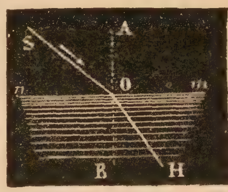
Plane reflecting surfaces are used in the *sextant* for measuring angular distances; in the *heliograph* for signalling when the sun's light is available; and in the *heliostat* for sending solar light in a constant direction. Silver mirrors reflect 90%, and amalgam only 60%, of incident light.

Single Refraction.—Lenses.

What is refraction?

Refraction is the deflection or bending which a ray experiences in passing obliquely from one medium to another. If it passes perpendicularly, it is not bent. In Fig. 67 suppose the ray SO passes from air to water. It is bent in the direction O H. The angle B O H formed between the refracted ray and the perpendicular is the angle of refraction. We note that a ray in passing from a *rarer* to a *denser* medium is refracted *toward* the perpendicular. In passing from a *denser* to a *rarer*, it is refracted *from* the perpendicular.

FIG. 67.

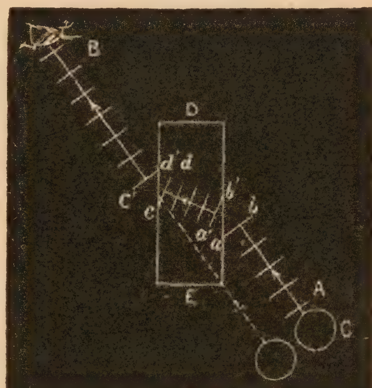


The perpendicular is any line drawn at right angles to the surface separating the two media.

What is the explanation of refraction?

It is due to the relative velocity of light in the two media. Let a series of parallel wave fronts leave an object C (Fig 68) and pass through a rectangular piece of glass. The point *a* of a given wave front *a b* is retarded, entering the glass first, while *b* retains its original velocity. The fronts assume new positions, much as soldiers execute a wheel. As they emerge *c* comes out first, and gains on *d*; so the emergent ray is parallel to the direction it had before entering the glass. It has been laterally displaced. If the ray had struck the glass perpendicularly, then all points of the wave would have been checked at the same instant, and suffered no refraction.

FIG. 68.



What are the laws of refraction?

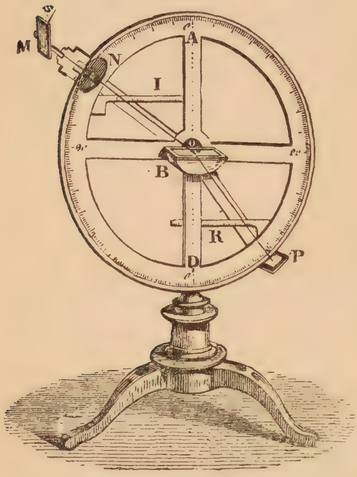
(1) *The ratio which the sine of the incident angle bears to the sine of the angle of refraction is constant for the same two media, but varies with different media.*

(2) *The incident and refracted rays are in the same plane, which is perpendicular to the refracting surface.*

These have been called Descartes' law.

In Fig. 69 let a ray of light pass in the direction of N o, striking a hemispherical vessel of water. It is here refracted in the direction o P. A D is perpendicular to the refracting surface, and let I and R be at right angles to it. Suppose the lengths of the radii o N or o P to be 10 in., and I to be $\frac{8}{10}$ as long as o N.

FIG. 69.



In trigonometry this fraction, or $\frac{\text{I}}{o\ \text{N}}$, is called the *sine* of the angle A o N. In a given case R might be $\frac{6}{10}$ the length of o P, which fraction, or $\frac{\text{R}}{o\ \text{P}}$, is the *sine* of P o D. The sine of the angle of incidence A o N is to the sine of the angle of refraction P o D as I : R, or as 8 : 6, or as 4 : 3. These lengths of I and R will always be the same for the same two media, and they also express the ratio of the velocities of the incident and refracted light.

What is the index of refraction?

This ratio of sines of the incident and refracting angles is the *index of refraction*. For air and water, as in Fig. 69, it is $\frac{4}{3}$. From water into air the index is $\frac{3}{4}$. From air to glass it is $\frac{3}{2}$; from air to diamond, $\frac{5}{2}$.

When one of the media is a vacuum the refractive index is greater than unity, and is called the *absolute index of refraction.*

Absolute	index	of vacuum,	1.
"	"	air,	1.000,294.
"	"	crystalline lens,	1.384.
"	"	diamond,	2.47 to 2.75.

What are some of the effects of refraction?

Place a coin on the bottom of an empty basin, so that it is just out of sight of an eye peering over the edge. Now fill the basin with water, and the coin has become visible. The ray of light from the coin is now bent at the surface of the liquid and strikes the eye. Apparently the bottom of the vessel is elevated and the water shallower. Thrust a stick obliquely into water, and it will appear shortened and bent, and the immersed portion elevated.

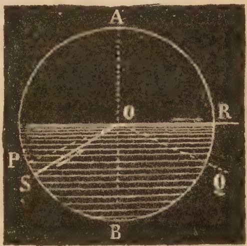
The stars, sun, and moon are visible to us when below the horizon. The atmosphere is denser nearer the earth, and rays coming through it are bent toward us, seeming to raise the heavenly body. This elevation is about $\frac{1}{2}°$ for our climate.

Twilight is due both to refraction and reflection by our atmosphere.

Explain the critical angle and total reflection.

Any ray can get from a rare to a denser medium, but not all can pass from a dense to a rarer one. Let rays pass from water to air (Fig. 70). As the angle between B O and S O gets larger the refracted ray will get nearer and nearer to the surface O R, until finally the angle of incidence S O B will correspond to an angle of refraction A O R, which is a right angle, and the refracted ray O R passes parallel to the surface of water. This angle S O B is the *critical* or *limiting angle.* It is such an *angle that will produce a refracted ray of 90°.* The sine of this angle multiplied by the index of refraction = 1. For any greater angle, as P O B, the incident ray cannot emerge, but undergoes *total reflection* in line

FIG. 70.



of O Q. This always occurs when the rays in the denser medium are incident at an angle *greater* than the critical angle.

The critical angle of water to air is 48° 35′.
" " glass " 41° 48′.
" " diamond " 23° 41′.

The critical angle diminishes as the refractive index increases. The brilliancy of the diamond and the lustre of cut glass are due to this internal reflection. They are more brilliant as the critical angle is less, for this allows a greater number of rays to be totally reflected, and but few pass through. "Paste" diamonds are made of lead oxide and flint glass.

In Fig. 70 it is evident that all the incident light which passes from air to water in the angular space A O R is condensed by refraction into space S O B of $48\frac{1}{2}°$, or the whole light that passes into water is condensed into 97°. A diver can see overhead only in a circular aperture of limited diameter. Beyond this circle he sees reflected the various objects on the bottom.

The *illuminated fountain* shows the principle of total reflection. Light is admitted from behind, and totally reflected from one surface of the stream to the other, and only appears as a round spot at the bottom of the receiving basin.

Explain the mirage.

The *mirage* is an optical illusion by which inverted images of distant objects are seen as if below the ground or in the atmosphere. It is a phenomenon of refraction, and most seen in hot countries.

The layers of air next the earth are most heated, and so less dense. The rays from some tall object are refracted less and less as they approach the earth, until they finally reach the eye as though coming from beneath the ground.

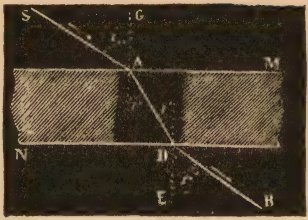
Mariners sometimes see such images in air, due to the same cause, but in a contrary direction, the lower layers of air being colder and denser from contact with water.

Show the path of a ray through a medium with parallel sides.

The emergent ray is parallel to the incident ray. Let ray S A be

oblique (Fig. 71); draw the perpendiculars at points A and D. Ray A D is reflected toward the perpendicular, and D B from it. The external angles i and r' are equal, as are the internal ones i' and r. If ray S A should be perpendicular to M N, it passes straight through without deflection. (See also Fig. 68.)

FIG. 71.



Show the path of a ray through a prism.

An optical prism is any transparent medium comprised between two plane surfaces inclined to each other. Those used for experiment are generally right triangular prisms of glass (Fig. 72). Their

FIG. 72.

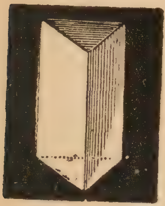
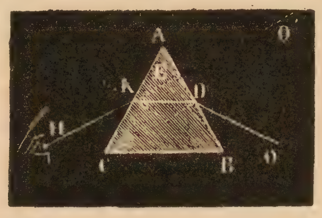


FIG. 73.



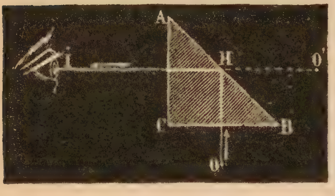
principal section is a triangle (Fig. 73). The angle A of the inclination of the two faces is the *refracting angle.* Let O D be incident at D. It will be refracted twice in the same direction, always toward the base of the prism. At D it is refracted toward the perpendicular in a dense medium; at K from the perpendicular in a rarer medium. The eye sees the object O at O′. The angle O E O′ is the *angle of deviation.* There is an angle of deviation less than any other, and this *minimum deviation* takes place when the angles of emergence and incidence are equal.

Show the path of a ray in a right-angled prism.

Prisms whose refracting angle is a right angle totally reflect the rays. Their section is a right-angled isosceles triangle. Ray O H (Fig. 74) enters the glass without refraction till it reaches H. It is

here totally reflected, striking face A B at an angle of 45°, which is greater than the critical angle of glass—viz. 41° 48′. Thus the hypothenuse surface A B acts like a perfect plane mirror, and the eye sees the image at O′.

FIG. 74.



Bisulphide of carbon is the best liquid for prisms, being of high refractive power. It is liable to stratify.

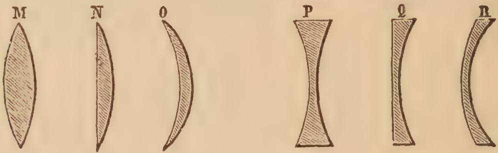
Lenses.

What are lenses?

Lenses are transparent media bounded either by two curved surfaces, or by one plane and one curved surface.

They may be spherical, elliptical, cylindrical, or parabolic. Those used in optics belong to the spherical type. They are made either of crown glass, which is free from lead, or of flint glass, which contains lead and is more refractive. There are six kinds: three that are thicker in the centre than at the edges, and are *converging*

FIG. 75.



lenses; three that are thinner at the centre than at the edges, and are *diverging* lenses. M is *double convex;* N is *plano-convex;* O is *converging concavo-convex;* P is *double concave;* Q is *plano-concave;* and R is a *diverging concavo-convex.* O and R are also called *meniscus lenses;* their two centres of curvature are on the same side.

Define certain terms employed to describe lenses.

M and P (Fig. 75) will only be considered, as showing the properties of each group. The centres for the spherical surfaces are called

the *centres of curvature*, and the straight line connecting them is the *principal axis*. With every lens there is a point on the principal axis called the *optical centre*. Every ray of light passing through it experiences no angular deviation. In double convex and double concave lenses this point is halfway between their respective curved surfaces—*i. e.* inside the substance of the lens. In lenses with one plane face this point is at the intersection of the principal axis with the curved surface; in the meniscus it lies outside the lens.

A *secondary* axis is any line passing through the optical centre and not through the centres of curvature.

The first group of three lenses may be supposed to be made up of a succession of prisms, with their summits outward, and their bases make the lens thick at the middle.

In the second group the bases are outward. Thus the first group ought to condense the rays, as a ray traversing a prism is deflected toward its base. The general effect of all convex lenses is to converge transmitted rays; concave lenses scatter them. Convex lenses and concave mirrors go together in producing similar effects; so do concave lenses and convex mirrors.

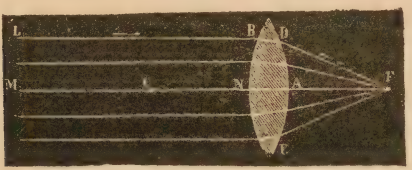
How are foci produced by double convex lenses?

The *focus* of a lens is the point where refracted rays or their prolongations meet.

The *principal focus* is the point where parallel incident rays meet after refraction.

The *real* focus is formed on the side of the lens opposite to the

FIG. 76.



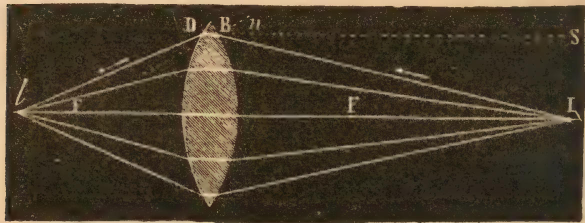
luminous body; the reverse of the case for concave mirrors. In Fig. 76 let the incident rays be parallel. Draw perpendiculars to points

B and D from their respective centres of curvature. Ray L B, in approaching the perpendicular at B and in diverging from it at D, is twice refracted toward the axis, which it cuts at F. All the parallel rays will be brought to this point. The distance A F is the principal focal distance.

In ordinary lenses the principal focus coincides very nearly with the centre of curvature; in plano-convex lenses the principal focal distance is twice that of a double convex lens.

Again, let luminous rays diverge from L (Fig. 77). The angle of incidence is here greater than that for a ray parallel to the axis,

FIG. 77.



as S B. The lens has not the power to bend the emergent ray down to F, but only to *l*. All rays from L will approximately intersect here, and these two points, L and *l*, are *conjugate* foci. A luminous point at either one is focused at the other. When L coincides with F, the emergent rays will be parallel to the axis and form no focus.

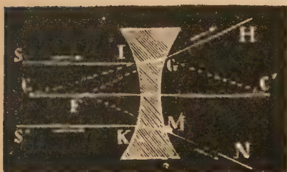
A double convex lens has a *virtual focus* when the luminous object is between the principal focus and the lens, and it is on the *same side of the lens as the luminous body.* The emergent rays diverge and cannot produce a real focus, but their prolongations will intersect on the axis.

How is a focus formed with a double concave lens?

This lens can only form a virtual focus, just as a convex mirror did. In case of lenses a virtual focus is always on the same side as the luminous body; in case of mirrors always on the opposite side.

In Fig. 78 the ray S I is refracted toward the perpendicular C I, and on emerging from the perpendicular G C′, being bent twice from the axis. The refracted rays form a divergent pencil, the prolongations of which intersect at some point F, called the *principal virtual focus.*

FIG. 78.

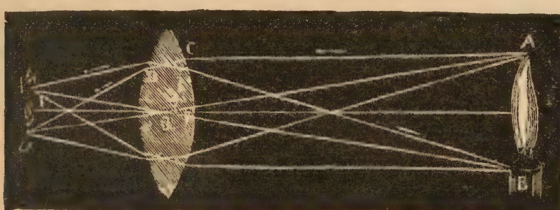


Convex lenses are often called "burning-glasses," from their power to focus heat rays.

How are images formed by double convex lenses?

The images will be real or virtual in the same cases that the foci were. Let object A B be beyond the principal focus (Fig. 79).

FIG. 79.



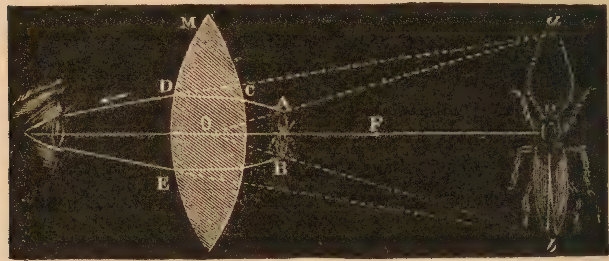
First draw the principal axis and the secondary axes A *a* and B *b*. Any two of the many rays from A will determine where its image *a* is to be. The two easily traced are one along A *o a*, and one A C parallel to the principal axis. The latter is refracted so as to pass through F, and intersects the secondary axis at *a*. This is the conjugate focus of A. Similarly for B and all intermediate points, and a *real inverted* image is formed at *a b*, between the secondary axes. Conversely, if *a b* were the luminous object, its image would be A B.

Two consequences important for the theory of optical instruments follow from this: that—1st, *If an object, even a very large one, is at a sufficient distance from a double convex lens, the real and inverted image which is obtained of it is very small; it is near the principal focus, but somewhat farther from the lens than this is.* 2d, *If a very small object be placed near the principal focus, but a little in front of it, the image which is formed is at a great distance; it is much*

larger, and that in proportion as the object is near the principal focus. In all cases the object and the image have the same proportion as their distances from the lens.

A Virtual Image with a Convex Lens.—Suppose the object A B is between the lens and the focus. Here, again, draw principal and secondary axes (Fig. 80). Ray A C on emerging diverges from sec-

FIG. 80.

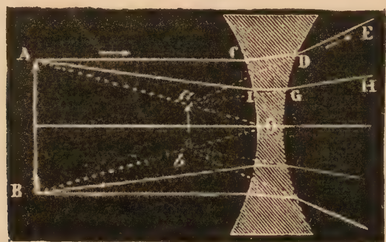


ondary axis O *a*. The prolongation of this ray, however, will cut O *a* at *a*. A similar point is found for B; so the image is between *a* and *b*.

The image of an object placed nearer the lens than the principal focus is *virtual*, *magnified*, and *erect*. A convex lens thus used is a *simple microscope*.

The principle illustrated in Fig. 79 is that of the *telescope*.

FIG. 81.



How are images formed by double concave lenses?

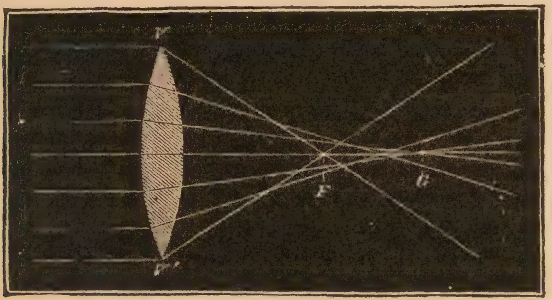
These give only virtual images, whatever the distance of the object. Let A B be placed in front of such a lens (Fig. 81). Draw

secondary axes for A and B. The emergent rays diverge, and the points where their prolongations cut the secondary axes determine *a b*. Hence images formed by double concave lenses are always *virtual*, *erect*, and *smaller* than the object.

What is spherical aberration by refraction?

When the aperture of a lens does not exceed 10° or 12°, all its refracted rays intersect at one point. When the aperture is larger, the rays coming from near the edges will intersect at a point F nearer the lens than G, which is the focus of the other rays (Fig. 82).

FIG. 82.



This is spherical aberration by refraction, analogous to that by reflection. Lenses which are free from spherical aberration are said to be *aplanatic*. This defect is very objectionable in all lenses, especially in photography, where the image should be distinct near the edges as well as at the centre. It is partly remedied by placing diaphragms before the lens, or by using two lenses a little distance apart, or by grinding the lenses, or by combining segments of spheres of different radii.

As an *application of lenses* and mirrors may be mentioned the laryngoscope, where a concave mirror or a convex lens aided by a reflector may converge the rays into the pharynx.

Summary and Comparisons.

Reflection is the term used for mirrors;
Refraction is the term used for lenses.

With the mirror the true rays are turned back; hence the principal focus and real images are all on the luminous side of the glass. With the lens the rays pass through and are bent; hence the principal focus and real images are all on the far side of the lens.

The principal focus of a concave or a convex mirror is about halfway between the centre of curvature and the mirror.

The principal focus of a double convex or a double concave lens about coincides with the centre of curvature.

No heat or light rays centre at a virtual focus; a virtual image cannot be cast upon a screen. The eye is the only apparatus which detects it, vision running along the directions of the real rays, which are on the other side of the mirror or lens.

Concave mirrors and convex lenses have real, virtual, and conjugate foci.

Convex mirrors and concave lenses can have only virtual foci.

The principal axis of a curved mirror passes through the centre of curvature and the centre of the mirror. The principal axis of doubly-curved lenses connects the two centres of curvature.

The secondary axis of a mirror must pass through its centre of curvature.

The secondary axis of a lens must pass through its optical centre, and *not* through its centre of curvature.

Concave mirrors and convex lenses converge incident rays; convex mirrors and concave lenses scatter them.

The image of an object placed beyond the centre of curvature is *real, inverted, and smaller* than the object. With the concave mirror it is located between C and F; with the convex lens it is beyond F.

If the object is at C in either case, the image is formed at C. If the object is between C and F, the image will be *real*, *inverted*, and *larger* than the object and beyond C.

If the object is at the focus of either, the reflected or refracted rays will be parallel, and no image be formed.

If the object is between F and the mirror or lens, the image is *virtual*, *erect*, and *magnified*. In case of the concave mirror it is back of it; in case of the convex lens it is on the same side as the object.

Convex mirrors and concave lenses *always* produce images which are *virtual*, *erect*, and *smaller* than the object. These images are behind the mirror and in front of the lens.

CHAPTER XVI.

DISPERSION AND THE SPECTROSCOPE.

What is dispersion?

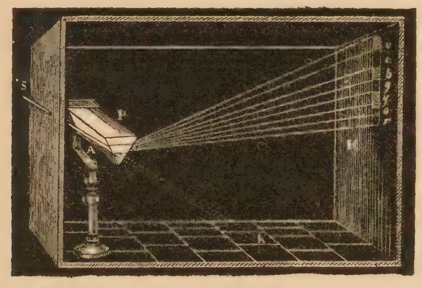
The phenomena of refraction are not so simple as has been assumed. When white light, like that of the sun, passes from one medium to another, it is decomposed into several kinds of light, a phenomenon called *dispersion.*

Dispersion is the unequal refraction of different wave lengths. Sir Isaac Newton was the first to study rainbow colors in 1675.

Let a ray of sunlight enter a dark room through a slit in a window-shutter. This slit should be about 1 in. long and $\frac{1}{25}$ in. wide, and near it may be placed an achromatic double convex lens for concentrating the rays.

The pencil of light tends to form a round colorless image of the sun at K (Fig. 83). Interpose in its path a flint-glass prism ar-

FIG. 83.



ranged horizontally with its base uppermost. The emerging pencil is refracted toward its base, and produces on the screen a colored ribbon rounded at the ends and called the *solar spectrum.* There is really an infinity of tints, but seven colors are usually distinguished. From above down they are *violet, indigo, blue, green, yellow, orange, red,* their initial letters spelling the unknown word *vibgyor.*

The violet rays are refracted the most, and the red least. Violet also occupies the greatest extent in the spectrum of any one color, and orange the least. The spectrum is in part produced by an innumerable series of overlappings of the image of the aperture. Newton did not find this out, but Wollaston did, and used a very narrow slit, as mentioned above.

The refracting angle of the prism should be about 60°. Prisms of different substances produce the same colors in the same order, but the lengths of the spectra will vary. Some substances have a greater dispersive—*i. e.* refractive power—than others. Flint glass makes a spectrum of double the length that crown glass does.

Spectra from artificial lights rarely contain all the colors, but they are colors belonging to the solar spectrum, in the same order, but with modified intensity. A yellow flame produces a spectrum in which the yellow tint predominates. With a prism we never get the exact extent of each color due to its wave length. This is given by the diffraction grating. (See p. 200.)

What is the explanation of the production of the spectrum?

The colors of the spectrum are simple, and cannot be further decomposed. A pencil of violet rays on passing a second prism will be refracted, but will be violet still. The simple colors have different degrees of refrangibility. In comparing their indices of refraction, that of the yellow light of sodium is taken as the standard.

The cause of the difference in refrangibilities—*i. e.* the cause of color—depends upon the number of waves emitted in a second of time, or on their corresponding wave-lengths. Numerous waves go with a short wave-length. In a dense medium like a prism the short waves are more retarded than the long ones, and hence refracted more. Violet has short waves of about $\frac{1}{65000}$ in., and red has longer ones of $\frac{1}{33000}$ in. The eye is able to appreciate about this range of wave-length. There is a limit to its sensibility, and there is much more to the spectrum than can be appreciated by sight.

How may white light be recomposed?

We have ascertained its composition by analysis; can it be verified by synthesis?

It may be reproduced in six different ways:

(1) By a prism;
(2) By a double convex lens;
(3) By a concave mirror;
(4) By a series of mirrors;
(5) By a rotating disk;
(6) By an oscillating prism.

(1) Let the spectrum formed by one prism fall upon a second of the same material and refracting angle, but inverted. The latter will reunite the colors, and the emergent ray of white light is parallel to the first one.

(2) Let the spectrum fall on a double convex lens or on a glass globe filled with water, and a white image of the sun will be formed on a screen placed at the focus.

(3) Same result as in (2).

(4) Let the seven separate colors strike the plane surfaces of seven little mirrors, which can be inclined in all directions. The reflections of these seven colors may be superimposed upon a screen, and a single white band is obtained.

(5) Newton's disk does the same by mixing the colors in the eye. The colors are arranged on the disk in proper proportions, and it is then rapidly rotated, giving an effect of grayish white. These are not properly prismatic colors, but pigments, or a pure white would result.

(6) If a prism upon which the sunlight falls be made to oscillate rapidly, so that the spectrum oscillates rapidly, the middle of the spectrum appears white.

Explain the color of bodies.

Color is not a quality of the object illuminated. "All look alike in the dark." If a white object in the dark be successively illuminated by the prismatic colors, it will appear violet, indigo, blue, etc. Those bodies which reflect or transmit all the colors in the proportion in which they exist in the spectrum are white, those which reflect or transmit none are black. Between these two limits are all possible tints, according as bodies reflect or transmit some colors and absorb others. A body appears yellow because it absorbs all the

colors except yellow, and this it reflects or transmits to our eyes. (If transmitted the body is transparent.)

When houses are painted color is not applied to them. Pigments are applied which have the property of absorbing all the colors except that one we would have the house appear.

What are complementary colors?

White can be produced in other ways than by mixing all the colors. If we can get the coincident action of two or more colors on the retina, it gives a single impression which cannot be resolved. On a black surface, about 2 in. apart, place two small bits of paper, one yellow and the other indigo-blue (Fig. 84). In a vertical position above and between them hold a slip of plate glass. Looking obliquely through it, you may see one paper by transmitted light and the other by reflection. The two may be made to overlap in the eye, when both colors apparently disappear, and the color resulting from their mixture takes their place—viz. white or gray. White can always be compounded of two tints, which are called the *complementary colors.*

Fig. 84.

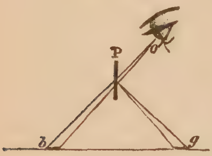
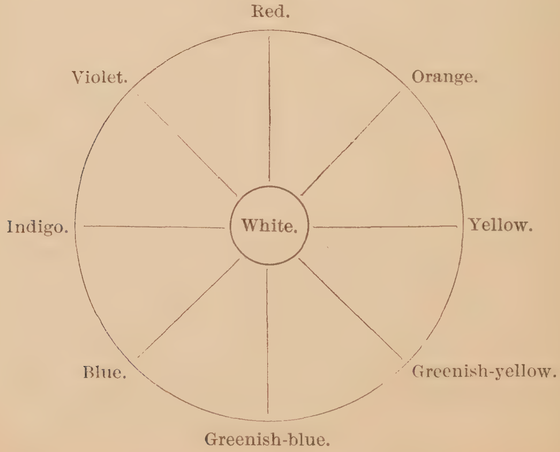


Fig. 85.



In the wheel of Fig. 85 those colors at the ends of each diameter are complementary. By splitting the green and making eight colors from the seven, they follow in regular order.

Again, on a white background lay a piece of blue paper. Look at it steadily for a few seconds, and then suddenly remove it. In its place will appear the image of the paper, but colored yellow. It is the *after-image*. If any other color in the circle be taken, the after-image will be the color that stands opposite. The explanation is that when we look at blue for a time the eye becomes fatigued by this color, while it is fully susceptible to the others. So when it is brought to look at white, which is a compound of yellow and blue, it receives a vivid impression of the former and a faint one of the latter.

What is the effect of mixing colors?

Mixed colors are those produced by the combination of two or more colors. If green is mixed with red in varying proportions, it will produce any of the colors between these two on the diagram.

Green mixed with violet produces any of the colors between these two, and violet and red produce purple.

So from *red*, *green*, and *violet* all possible colors may be constructed. These are called the *three primary* or *fundamental colors.*

There are three points to discriminate in regard to color: *tint*, due to a definite refrangibility; *saturation*, due to a greater or less admixture of white light; and *intensity*, due to amplitude of vibration.

How do pigment colors differ from prismatic?

The spectral colors blue and yellow produce white. If, however, a chrome-yellow pigment and an ultra-marine blue be mixed, it *leaves* green: no white is formed. The reason is that with pigments we have a case of subtraction of colors, and not of addition. Let the blue solution of copper sulphate be interposed in the path of the light which forms a solar spectrum: we shall find that the red, orange, and yellow rays will be cut out. Interpose a yellow solution of bichromate of potash, and the blue and violet rays will be absorbed. Both solutions will subtract all the colors except the green.

Cancelled by blue solution, ~~R~~ ~~O~~ ~~Y~~ G B V.
" yellow " R O Y G ~~B~~ ~~V~~.
" both " ~~R~~ ~~O~~ ~~Y~~ G ~~B~~ ~~V~~.

Blue glass is opaque to yellow light, and is used in testing for potassium.

What is homogeneous light?

The light from luminous bodies is seldom quite pure; *i. e.* it will contain more than one color. A *homogeneous* light is *monochromatic*, has but one color, and vibrates in one particular wave-length. Sodium or common salt in a Bunsen's flame gives a homogeneous yellow light of great purity.

Glass colored with suboxide of copper absorbs nearly all rays but the red. A nearly pure blue comes from transmitting ordinary light through an ammoniacal solution of $CuSO_4$.

What are the properties of the spectrum?

It has luminous effects;
It has heating effects;
It has chemical effects.

Luminous.—The greatest intensity of light is in the yellow part of the spectrum, and the least in the violet.

Heating Effects.—By moving Melloni's thermo-multiplier from the violet end of the spectrum to the other, a higher T. will be noted as the red is approached. With a prism of crown glass the maximum T. is in the middle of the red, but it varies somewhat with the nature of the prism.

The heating effects go beyond the visible red, and these invisible rays are called *calorific*, or ultra-red, rays. They have longer wave-lengths than the luminous rays.

Chemical Effects.—Light acts as a chemical agent on many substances. It blackens chloride of silver. A paper wet with this solution suffers no change in the dark, but exposed to the spectrum it is turned black unevenly. The change is slowest in the red, but increases till a maximum is reached in the first part of the violet. It ceases beyond the visible limit of the violet.

These ultra-violet rays are more refrangible and of shorter wave-length than the luminous rays. They are called *chemical* or *actinic*

rays. If we call the whole length of the visible and invisible spectrum 14 in., the actinic part will be 3 in. long, the luminous part 1 in., and the thermic part 10 in. So we see only about $\frac{1}{14}$ of the whole spectrum.

Iodine and bisulphide of carbon are opaque to the light part of the spectrum, but not to the heat or chemical action. A reddish-yellow light or glass colored with oxide of Cu is opaque to chemical rays, and useful in the photographer's "dark closet." A solution of alum and water is opaque to heat rays. A capsule of alum-water prevents the burning of the specimen in powerful microscopes.

What are Fraunhofer's lines?

Rays are wanting for several grades of refrangibility, and throughout the luminous solar spectrum a number of black lines are seen. This only occurs when the spectrum is formed through a slit, not if a round hole be the aperture. Wollaston first observed these lines in 1802.

Fraunhofer, an optician of Munich, gave a detailed description of them in 1815. He distinguished the most important by certain letters of the alphabet. About 576 have been mapped and photographed, and are constant for solar light. Brewster and others have counted 2000 to 3000. Several supposed to be single have been shown to be compound.

What is spectrum analysis?

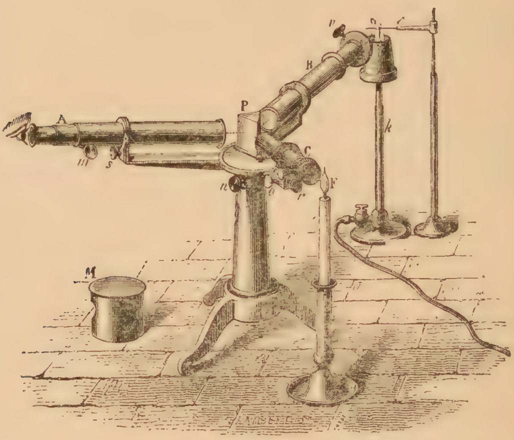
No two substances give spectra having the same combination of lines. *Spectrum analysis* consists in determining the presence or absence of given substances in a luminous vapor by the presence or absence of their characteristic lines in the spectrum. Likewise, substances present in the solar atmosphere can be determined by reversed lines of the solar spectrum.

Bunsen and Kirchhoff in 1859 were the first to investigate the lines of a spectrum with a view of making their observations a method of analysis. They found that salts of the same metal when volatilized always produced lines identical in color and position, but different in color, position, or number for different metals, and that an exceedingly small quantity of the metal is sufficient thus to detect its presence.

Describe the spectroscope?

This is an apparatus devised by these men for studying the spectrum. The necessities are—a slit, a lens, a prism, and a telescope; others add a candle to reflect a scale. The usual form consists of three telescopes mounted on a common foot whose axes converge toward a prism P of flint glass (Fig. 86). Telescope A is for the

FIG. 86.



observer, B conducts the light under investigation, and C gives an image of a very fine scale by which to measure the relative distances of the lines. The rays from light G pass an adjustable slit and fall on the lenses of B, emerge in parallel lines, and strike prism P. They are refracted and dispersed, forming a spectrum, an enlarged image of which is seen by the eye through A.

At the end of C is placed a *micrometer*, which is a photographic negative on glass of a millimetre scale. The scale is illuminated by candle F, and its rays, made parallel, are reflected by the face of the prism, forming an image of the scale in front of that of the spectrum. Thus the relative distances of the spectral lines can be measured and recorded. Telescope B is called the *collimator*.

The spectra of two flames can be compared at the same time—one known and one unknown. Rays from the second one are ad-

mitted into B above the other. They come from a flame placed at the side, and are turned into B by means of a right-angled prism.

The flames are usually a jet of ordinary gas from a Bunsen's burner in which all the carbon is fully burned. Into this jet is passed a platinum needle dipped beforehand into a salt of the metal to be studied.

Some metals cannot be thus vaporized. The electric light will not vaporize Fe or Al. It can be done by taking electric sparks between wires of the metal whose spectrum is required; best obtained by a Ruhmkorff's coil. This will vaporize anything, bringing all metals under the sphere of spectrum observation. Instead of one prism, a *train of prisms* may be used, increasing dispersion, but lessening the illumination.

What is a direct-vision spectroscope?

By combining prisms, light is not refracted, but may be decomposed and produce a spectrum. Two flint- and three crown-glass prisms are placed in a single brass tube which moves in a second one. At one end is an adjustable slit, focusing upon which is an achromatic lens between the slit and the prisms. The spectrum is viewed from the opposite end.

What are some of the discoveries by the spectroscope?

A Na spectrum contains neither red, orange, green, blue, nor violet, but is marked by a very brilliant yellow line. $\frac{1}{200000000}$th of a grain of Na is enough to produce this yellow line; so it is very difficult to avoid its appearance, a little dust in the air producing it. With the first experiments its omnipresence was convenient as an established landmark.

Whenever a new line is found, not before mapped or recorded, its investigation may lead to the discovery of a new element.

First after making their instrument Bunsen and Kirchhoff discovered in mineral water *rubidium*, and then *cæsium*, the former distinguished by two brilliant dark-red lines, the latter by two blue ones. Then *thallium* was found independently by Crookes of England and Lamy of France, characterized by a single green line. Then followed *indium* and *gallium*, the former having a line in the indigo.

The character of spectra changes with temperature and pressure.

Spectra of gases are best obtained by passing an electric spark through tubes containing the rarefied gas—viz. through Geissler's tubes.

Mention the kinds of spectra.

(1) Continuous;
(2) Bright line;
(3) Dark line;
(4) Bright band;
(5) Dark band.

(1) All *incandescent solids* and *liquids* give a continuous spectrum; *e. g.* the candle, kerosene lamp, gas-jet, or electric light. The incandescent solids in these cases are minute particles of carbon.

(2) Bright line or discontinuous spectrum is produced by *incandescent gases* or *vapors.* This may be called a *positive* spectrum.

(3) The dark line or sun spectrum is produced by the sun, moon, planets, and fixed stars. It may be called *absorption* or *negative* spectrum.

(4) The *bright* or *positive-band* spectrum is given by comets and nebulæ.

(5) The *dark* or *negative-band* spectrum is formed by substances of animal chemistry, as blood, albumin; also by wine, beer, and salts of didymium. Useful in physiology and pathology and medico-legal investigations.

What is the explanation of the dark lines of the solar spectrum?

In front of an electric light let there be placed a flame colored with Na, and let rays from both lights enter the spectroscope. Where we would expect the yellow *bright line* of Na is found a *dark line.* In the same way, if the electric light traverse vapors of K or Ba, the bright lines which they would have produced are replaced by dark ones; hence the name *absorption* spectra. It appears that the vapors of certain substances quench or absorb the very same rays which they are capable of emitting. The Na vapor absorbs from white light those rays having the same refrangibility as its own; others pass unchanged. It is here made possible to apply spectrum analysis to astronomy.

Four hundred and sixty bright lines of Fe are known. Kirchhoff found by direct comparison that the bright lines which characterize Fe correspond to dark lines in the solar spectrum. He found the same to be the case for Na, Mg, Ca, Cu, Ni, H, and others.

We may draw important conclusions with regard to the constitution of the sun. Since solar spectra have dark lines where Fe, Na, etc. give bright ones, it is probable that around the body of the sun is a vaporous envelope which, like the Na flame in the experiment, absorbs those rays from the body of the sun which the envelope, called *chromosphere*, is capable of emitting. The central nucleus or *photosphere* emits all wave-frequencies, and would give a continuous spectrum.

One of the triumphs of spectrum analysis has been the discovery of the nature of the sun's flames or protuberances: they sometimes shoot up 70,000 miles high. The eclipse of 1868 was especially studied for this purpose. Draper found that the sun's vapor contained free O and H. Steam can be passed through a red-hot platinum tube, and O and H will pass out the other end, and yet not be water. This is called *dissociation*, and these two gases are present in that way in the sun's vapor. These protuberances can now be investigated at any time without waiting for an eclipse. Draper concluded that the sun's spectrum was partly bright line and partly dark line. White light comes from the solid interior of the sun, and a bright-line spectrum from its envelope. The combination gives a dark line. He also thinks that sunlight is blue really, but a certain portion is filtered out and gives us white.

The *bright-band* spectra are hardly explainable, but probably come from an incandescent gas. Comets have bright bands rather than lines, perhaps from rapid motion. The star Sirius has great velocity and gives a bright-band spectrum. It has been thought that all nebulæ were stars, but the spectroscope does not show it.

What is fluorescence?

Fluorescence is that property which some substances have of appearing colored blue when viewed in reflected light, and colorless when seen by transmitted light. By placing a vessel of quinine sulphate solution in different parts of the spectrum, beyond the violet end, rays of a beautiful blue color can be seen. The usually invisible ultra-violet rays have changed their refrangibility, have

lessened their vibration speed, and toned down so we can see them. This property is confined almost wholly to the violet end of the spectrum. Fluorescence and phosphorescence probably differ only in degree.

What is chromatic aberration and its remedy?

As lenses are made up of a series of prisms with infinitely small faces, it is easy to see that a lens not only refracts light, but decomposes it like a prism, giving images with colored edges. This defect is due to the unequal refrangibility of simple colors, and is called *chromatic aberration.* There is really a distinct focus for each color: the violet rays, being most refrangible, find a focus nearer the lens than the red ones do.

Achromatism is the term applied to the phenomena of refraction of light without decomposition. By combining prisms of different refracting angles and of equal dispersive powers the dispersion of each is neutralized and the refraction not destroyed.

The base of one prism is applied to the apex of the other, so that dispersion takes place in contrary directions and is made nil.

How are achromatic lenses made?

They are made of two lenses cemented together, whose dispersion is equal and neutralized. The substances of which they are made have unequal dispersive powers, and so the two need not be of the same size and shape. One is a meniscus of flint glass of small angle, and the other a double convex lens of crown glass of large angle. Several lenses or prisms may be necessary to obtain perfect achromatism.

CHAPTER XVII.

OPTICAL INSTRUMENTS.

What are the optical instruments?

An optical instrument is a combination of lenses or of lenses and mirrors. There are three classes:

(1) Microscopes;
(2) Telescopes;
(3) Instruments of projection.

The two former yield virtual images, the latter in general give real images.

What is the principle of the simple microscope?

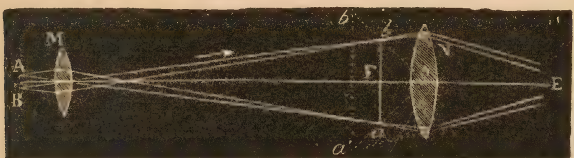
The simple microscope or magnifying-glass is merely a convex lens of short focal length. The object is placed between the lens and its principal focus, and the image is erect, virtual, and magnified, as in Fig. 80. The image is larger the nearer the object is to the focus.

Focusing is finding the distance of most distinct vision. Spherical aberration may be corrected by using two plano-convex lenses instead of one double convex, called *Wollaston's doublet.*

What is the principle of a compound microscope?

In its simplest form it consists of two condensing lenses, one with a short focus placed near the object, called the *object-glass* or *objective*, and the other, which is less condensing, is the *eye-piece* or *power*, being close to the observer's eye. The object A B (Fig. 87) is

FIG. 87.



placed a little beyond the principal focus of M. A real, inverted, and somewhat magnified image is formed at a b, which is between N and its focus F. So N produces the same effect on this image as a simple microscope would upon an object. It produces a' b', virtual and still more magnified, and inverted in regard to the object. A compound microscope is nothing more than a simple one applied, not to the object, but to its image, already magnified by the first lens.

Focusing is accomplished by changing the distance between the objective and the object, the distance between the eye-piece and the object-glass remaining the same. With telescopes, where objects are inaccessible, focusing is effected by varying the distance between the eye-piece and the objective.

Good microscopes have combinations of lenses for the correction

of spherical and chromatic aberration and for the production of high and low magnifying powers.

A *binocular* microscope is made with two barrels and two eye-pieces, but is not very practical for high powers.

It is not necessary here to describe the various mechanisms and accessories of a first-class microscope, the methods of illumination, the different kinds of stages, of stands, and of lenses.

How is magnifying power determined?

The measure of magnification is the ratio of the apparent diameter of the image to that of the object. This is *linear* magnification, and the *superficial* or whole measure of area is the square of the linear, for the area of a circle varies as the square of its diameter. If an object is magnified 40 diameters, its superficial magnification is 1600.

In a compound microscope the magnifying power is the product of the respective magnifying powers of the objective and of the eye-piece. If the first magnifies 20 diam., and the second 10, the total is 200.

A power of 1500 diam. has been obtained, but it ought not to exceed 500 or 600 to obtain well-illuminated images. This gives a superficial enlargement of 250,000 to 360,000 times that of the object. The power is obtained experimentally by placing a *micrometer* in front of the object-glass, and reflecting the image of its lines upon a screen upon which is another scale of millimetres. By comparing the two the magnifying power is deduced.

The absolute magnitude of objects can also be found. Since the magnifying power is the quotient of the size of the image by the size of the object, it follows that if we divide the size of the image by the magnifying power, we have the size of the object.

$$\text{Mag. power} = \frac{\text{size of image}}{\text{size of object}}. \qquad \text{Size of object} = \frac{\text{size of image}}{\text{mag. power}}.$$

Telescopes.

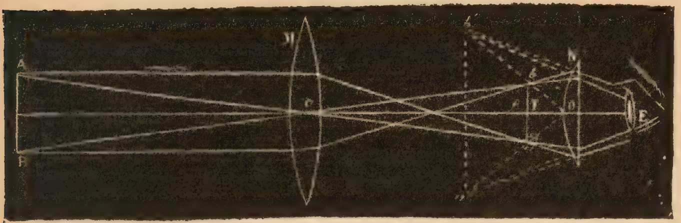
Describe the astronomical telescope.

Like the microscope, it consists of a condensing eye-piece and object-glass. The object-glass M (Fig. 88) forms between the eye-piece N and the focus of N an inverted image of the heavenly body.

The eye-piece, acting as a simple microscope, gives a virtual and highly magnified image of $a\ b$ at $a'\ b'$.

The construction is similar to that of the compound microscope, but with this difference. In the microscope both object-glass and

FIG. 88.



eye-piece magnify; in the telescope there is no magnification except by the eye-piece, which should be of very short focal length.

A smaller telescope, called the *finder*, is placed above the larger one, having a large field of view. For accurate observations of transits, etc., two *hair lines* or spider threads at right angles to each other are stretched across a circular aperture inside the tube. The object-glass is as large as possible, so as to collect a great deal of light from the distant object. The Clarks of Cambridge, Mass., are now making one for Russia four feet in diameter, the largest in the world. It requires several years to make one—great care and skill and empirical grinding. Telescopes are of such power that a ball 2 in. in diameter and 250 miles distant is distinctly visible if properly illuminated.

Describe the terrestrial telescope.

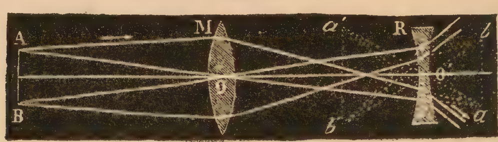
The simple microscope gives an erect image; the compound microscope and the astronomical telescope give inverted images, but the terrestrial telescope must have erect images. This is effected by two condensing lenses placed between the object-glass and eye-piece. The distance between these two remains constant. The inverted image is reinverted, and as such is magnified by the eye-piece.

What is the construction of the opera-glass and Galileo's telescope?

This is the simplest telescope of all, having only two lenses—an

object-glass and a diverging double concave eye-piece. It gives at once an erect image. Opera-glasses have the same combination. The eye-piece is so placed that the image formed by the objective would fall behind it, as at *a b* (Fig. 89). But the rays are refracted

FIG. 89.



and diverge, so that the eye sees a virtual image magnified and erect at *a′ b′*. This was the first telescope directed toward the heavens, and by it Galileo discovered the spots on the sun, the mountains of the moon, and Jupiter's satellites.

What is the principle of the chief reflecting telescopes?

The above are *refracting* telescopes, but before achromatic lenses were known the old style were *reflecting* telescopes, a concave metallic mirror being used instead of the object-glass.

Gregory's telescope consisted of a long tube closed at the observer's end by a large concave mirror with an aperture in it. Rays were reflected from this outward upon a second small mirror, thence back to the eye again at the aperture, thus traversing the tube three times.

Newton's telescope is similar. The large mirror is not perforated, but throws its rays upon a small mirror at an angle of 45°, which in turn sends the reflected rays toward an eye-piece situated in the side of the tube and not at the end.

Herschel's telescope has been a celebrated instrument. The mirror here is inclined, so that the image is formed on the lower side of the tube at the outer end. The light enters the tube over the observer's head, and is reflected back to him from the opposite closed end. This is a *front-view* telescope, and gives better illumination than the other reflecting ones. Herschel's great telescope was constructed in 1789, and was 40 feet long.

Instruments of Projection, for Forming Pictures of Objects.

The *camera obscura* has already been described. (See Fig. 52.)

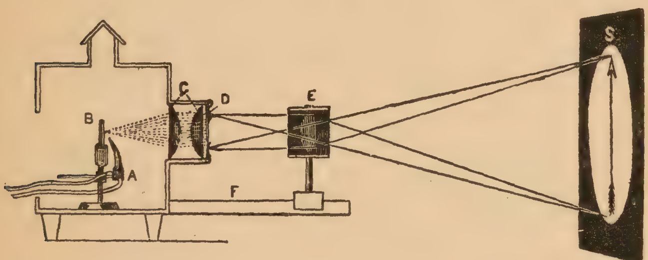
It was a toy until the photographers brought it out. The inverted image is formed upon a sensitized plate, the rays producing chemical action, and a picture is obtained.

The *camera lucida* is a small instrument depending on internal reflection, and used for tracing the outlines of an object.

Describe the magic lantern?

This is an apparatus by which a magnified image of a small object may be projected on a screen in a dark room. It is also called *stereopticon* and *megascope*, and is really a reversed camera obscura. The light generally used is the Drummond light, where a flame from an oxyhydrogen blowpipe is directed against a stick of lime, and raises it to a white heat. The electric light may be used. This light is in

FIG. 90.



the focus of a concave mirror situated posteriorly, which reflects the rays upon two plano-convex lenses at C (Fig. 90).

They illuminate a figure painted or photographed upon a glass *slide* at D. In front, upon a sliding piece at E, are two projecting convex lenses which produce a real, magnified, and inverted image on a distant screen. Of course the slide must be put in place inverted; then the image on the screen is erect, or it is corrected by a prism placed in front of E. Generally a bundle of glass plates is used in connection with the condensing lenses to give polarized light. *Dissolving views* are produced by two lanterns, which throw their images on the same spot. As the shade is raised from the lens of one it is lowered in front of the other.

The *solar microscope* is only a magic lantern illuminated by the

sun's rays regulated by the heliostat. It is used in a dark room, with the sunlight admitted through a shutter.

CHAPTER XVIII.

PHOTOGRAPHY.

What is photography and its history up to Daguerre?

Photography is the art of fixing the images of the camera obscura on substances sensitive to light.

That light produces chemical changes is well known in the fading of colors or seen by the chemical combination of H and Cl gas. All salts of silver are affected by light, especially by the ultra-violet rays.

Scheele, who discovered O, really discovered photography, and made some observations in 1777. Watt and Bolton in 1792 even made a few pictures, but Thomas Wedgewood in 1802 is known as the first man to take a picture. He and Davy put an opaque object upon a silver-chloride paper and exposed it to the sun. They got a white picture on a dark ground, but didn't know how to prevent the further action of light, and had to look at their pictures by candlelight.

In 1813, Niepce started out for success. His idea was something like that of an etching. Asphalt is soluble in various oils, but if exposed to a strong light Niepce found it was insoluble in oil of turpentine and oil of lavender. So he coated a Cu plate with varnish of asphalt or bitumen, exposed it to the object in strong light, and afterward washed off the soluble parts by oil of lavender. This gave a permanent image, a sort of heliograph.

Describe Daguerre's process.

Daguerre worked with Niepce and made a success in 1839. He used silver salts, and not asphalt. When the news came to this country that a new photographic process was discovered, scientists were slow to believe, as they had already been hoaxed by young Herschel's telescope. This was in 1835. John W. Draper of New

York, with a few hints from the other side, really reinvented daguerrotypes, and made better pictures than Daguerre ever did. Barnard took it up after Draper.

We may here mention the four steps necessary for the production of any permanent picture; Daguerre found them out partly by accident:

(1) Sensitize the plate;
(2) Expose the plate in camera;
(3) Develop the picture;
(4) Fix the picture.

Daguerre in (1) used a well-polished Cu plate coated with Ag. It was then exposed to iodine vapor, forming a layer of sensitive iodide of silver. (2) Next it was exposed in the camera, which had a large aperture. This exposure required 15 or 20 minutes, but was afterward reduced to 1 or 2 minutes by using accelerators in the iodide of silver, such as Br or hypobromite of Ca. (3) Next it had to be developed in a red or red-yellow light—*i. e.* light free from actinic rays. The plate is exposed to Hg vapor, which metal is deposited on the silver salt, most acted upon by the light, in form of globules imperceptible to the eye. The shadows or those parts least acted on are still covered with iodide of silver. This superfluous iodide is washed away in step (4) by hyposulphite of soda or common salt solution. This does not affect the metallic Hg, so the light parts of the image are Hg, and the shaded is the Cu plate, which still retains its lustre.

The first radical improvement was made here in America by "toning" the picture with a solution of chloride of gold.

What is a Talbot-type?

Fox Talbot of England gave the first idea of a negative. A *negative* is an image, usually on glass or paper, with reversed tints and a lateral displacement. The light parts of the object are dark on the negative, and *vice versâ.* They serve to produce a *positive*, which gives the natural lights, shades, and position. Talbot made waxed-paper negatives. He used iodide of potash on the paper and floated it in silver nitrate solution. It was then exposed, and next brushed

over with acetic and gallic acid, which fixed metallic silver on the parts most acted upon by light. It was then waxed.

An improvement on this method was to wax the paper before the picture was taken.

Describe the collodion or wet-plate process.

Scott Archer in 1851 used collodion on a glass plate as a vehicle for sensitive silver salts. Schönbein is noted for discovering ozone in 1840 and gun-cotton in 1841. There are three varieties made from cellulose by the action of HNO_3 and H_2SO_4.

$$C_{18}H_{30}O_{15} \text{ is cellulose;}$$
$$H - O - NO_2 \text{ is nitric acid.}$$

$$\text{Gun-cotton}\left\{\begin{array}{l} C_{18}H_{23}(NO_2)_7O_{15} \\ C_{18}H_{22}(NO_2)_8O_{15} \\ C_{18}H_{21}(NO_2)_9O_{15} \end{array}\right. \begin{array}{l} \left.\begin{array}{l}\\ \\ \end{array}\right\} \begin{array}{l}\text{soluble,} \\ \text{for making collodion.}\end{array} \\ \left\{\begin{array}{l}\text{insoluble;} \\ \text{very explosive.}\end{array}\right. \end{array}$$

So a less explosive kind of gun-cotton is dissolved in alcohol and ether, and makes collodion.

(1) *To Sensitize.*—Coat one side of a glass plate with collodion containing iodide or bromide of cadmium or KI. Plunge the plate into a bath of $AgNO_3$, about 30 gr. to the ounce, and sensitive iodide of silver is formed: $AgNO_3 + KI = AgI + KNO_3$. After about one minute the plate is taken out, drained, and put in a plate-holder. All this is of course done in the dark closet.

(2) Expose in a camera for one minute, a fraction thereof, or more according to light.

(3) Develop in the dark room by pouring over the plate a solution of protosulphate of iron or of pyrogallic acid, which reduces to a metallic state those parts of the iodide of silver most acted upon by the light: $6AgI + 6FeSO_4 = 6Ag + 2Fe_2(SO_4)_3 + Fe_2I_6$. When the picture is fully brought out, wash with water to stop further development.

(4) Fix, by dissolving off the AgI not acted on by light. Hyposulphite of soda does this. Where the shadows of the object were no Ag is deposited, and this part is left light. Wash well with

water to remove all "hypo;" dry and then varnish for preservation.

Pictures taken on tin are silver on a black surface, called tintypes, ambrotypes, or ferrotypes. They are positives.

So we have considered Niepce with his asphalt pictures, Daguerre with Hg. pictures on Cu, Talbot with paper negatives waxed, and Archer with collodion wet plates or negatives on glass.

What is the dry plate?

The wet plates are now wholly given up for dry plates. An emulsion is made of gelatin and bromide of silver. Sometimes albumin, collodion, honey, or glycerin is used for the vehicle. The emulsion is heated for 45 minutes; then strained and cooled and applied to glass plates of various sizes. These are packed by the dozen in boxes secure from light, and shipped all over the world to be used by the professional artist or the enthusiastic amateur. The sensitiveness of such emulsion is wonderful, and it is made of different degrees. Through an aperture of $\frac{1}{80}$ in. a picture may be taken in $\frac{1}{6000}$ sec. portraying unheard-of attitudes of trotting horses, jumping men, or flying birds.

Instead of coating glass with this sensitive gelatin, paper may be so treated, which has to be "stripped off" after the picture is developed.

Within two years a most perfect backing has been found in transparent celluloid. This is sold in long rolls called *films*, and used on a roll-holder in the back of the camera, and exposed in sections.

Photographs may be taken by electric or Mg light, as they possess actinic rays.

Can colors be photographed?

Orthochromatic plates which contain eosin are not merely sensitive to the ultra-violet rays; with these plates yellow objects, instead of appearing black, or blue objects appearing white, will appear in their true relation of brightness to one another, but not in color. This spring Prof. Lippman of the French Institute is said to have photographed colors and taken pictures of the spectrum. He finds two essentials necessary: (1) The sensitive substance must be spread in a state of almost infinite subdivision in a transparent vehicle, as

gelatin, albumin, etc. (2) The sensitive plate must be placed on the back of a reflecting surface. During exposure it is fixed in a carrier containing Hg which forms a plane mirror in contact with the plate. The whole secret lies in the Hg mirror, which changes the wave-lengths of the different colors and allows them to be reproduced. If successful, this will be one of the great advances of the age.

How are composite pictures taken?

These are obtained by getting the images of a number of photographs on a plate at the same spot, and then developing.

What is photo-micrography?

This is the process of taking pictures of microscopic objects. A micro-photograph means a microscopic photograph, one so small that it cannot be seen by the unaided eye. The same photo-micrograph cannot have high magnification, distinctness, and good illumination; one or the other has to be sacrificed. If not perfect, they are useful as guides and a basis for drawings.

For light there is nothing equal to sunlight introduced through a shutter, concentrated by a lens, and kept constant by a heliostat. With orthochromatic plates and sunlight the exposure need be only 1 or 2 secs. Almost as good pictures can be taken by artificial light from a series of five or six gas-jets arranged tandem and focused on the specimen by a reflector

This way was devised by Dr. Sternberg: A sheet of asbestos with a central aperture is placed between the lights and the microscope, to ward off too great heat. Use any good microscope whose tube can be placed horizontally. The eye-piece and end of the tube are placed in a blackened funnel which enters a camera with a long bellows. First focus the microscope on a certain part of the specimen; its real and magnified image is caught on the ground-glass back of the camera, and the microscope has again to be focused.

The farther the back is from the eye-piece the greater the diameter of the picture. Exposure may have to be 5, or even 10, minutes with artificial light.

How are positives made?

When once a negative is obtained, it may be used for *printing* an indefinite number of positives. To make *silver prints*, albumin-

paper is used impregnated with $NaCl$ and $AgNO_3$—*i. e.* with $AgCl$. This paper is sold in large sheets or in packages, and is placed upon the film side of the negative. Plate and paper are then placed in a printing frame, and that in the sun, so that sunlight passes through the glass and strikes the paper.

The nearly transparent parts of the negative let much light through, and give dark shadows on the print, and so the natural lights and shadows of the original are returned. The prints are toned with $Au\,Cl_3$, and fixed with "hypo," just as a negative was, otherwise they become black. They then should be washed several hours in running water, dried, trimmed, and mounted on card-boards.

Blue prints are good for machinery, architecture, or landscapes. The paper is impregnated with ferrocyanide of potassium and citrate of iron and ammonium. After printing they are simply soaked in water and then dried.

Bromide prints are used for enlargements.

Platinum prints are very beautiful. Paper charged with ferric oxalate is printed, and then developed by a platinum salt. There are also uranium prints, red prints, black prints, etc.

What is the artotype or Lambert-type?

A mixture of charcoal and gelatin is made, called *carbon tissue*, which is insensitive to light. This is sponged over with bichromate of potassium and exposed with the wetted negative upon it. The light strikes through the transparent part of the negative and makes the gelatin insoluble. The rest of the gelatin and carbon not acted on by the light can be washed off. This gives a positive called *artotype* (also written *autotype*) or gelatin transfer.

What are the different processes for making negatives?

(1) Talbot-type, paper negative waxed;
(2) Waxed-paper process;
(3) Albumin on glass;
(4) Wet-plate collodion;
(5) Dry plates and films;
  gelatin emulsion,
  collodion emulsion, etc.

How are positives obtained?

Directly by
- Daguerrotype,
- Tintype,
- Dry plates by treating the negative with KCN.

Indirectly by a negative:
- Silver prints,
- Blue prints,
- Bromide, "platinum," etc.,
- Artotype, "carbon tissue,"
- Exposing dry plate to a negative and developing.

What are the photo-mechanical processes?

Most depend on the carbon tissue and gelatin film.

(1) Woodbury-type;
(2) Callotype (color);
   Albert-type, Heliotype, Artotype } from gelatin, and printed with printer's ink.
   Indo-tint.
(3) Gelatin transfer process:
   Photo-lithograph,
   Photo-zincograph,
   Photo-electrotype.
(4) Relief process:
   Photo-engraving, type-metal relief;
   Photo-electrotype, copper-metal relief.
(5) Intaglio process:
   Photo-etching,
   Photo-electrotype.

(1) To make a Woodbury-type the gelatin film is used, which stands up in relief where the light has struck through the negative. This film may be pressed into zinc plates or into paper by hydraulic power, and a mould is made. From this a sort of leather picture can be made, used a good deal in illustrating books.

(2) *Callotype.*—Albert of Munich placed the gelatin film on glass, and used it for printing with printer's ink. Printer's ink may be

used of two kinds—a thick, and a thin one giving half tones and tints. The heliotype is only the thin gelatin film removed. Old etchings may be reproduced in this way.

Silicate of soda with the gelatin preparation is more available for the printer's ink.

The photo-lithograph is made by drawing a picture on limestone with crayon. Wet it with gum-water, which the stone absorbs where there is no crayon. Lay a paper on the stone and put it in the press, and you have a stone picture on paper. Get a negative from a steel engraving, then a transfer on paper, and that on stone, and then we can print 1200 per hour. Or a gelatin relief is made from the negative, and from that a plaster of Paris cast, into which type-metal is poured. Knock off the plaster, and reproductions are printed from the type-metal.

Photo-electrotyping does not apply to the human face—must have distinct lines. First get a gelatin relief from a negative, which is impressed on wax, and the wax mould is electroplated. (See p. 280.) Further descriptions must be sought in special works on these subjects.

I would here urge the importance of the photographic art to the medical man. A picture "before and after" tells much more than a word picture, and is exact. Lip motion is photographed for the study of deaf-mutes. Any one can readily learn the whole process without an instructor, and can take good pictures of anything or anybody with an outfit costing $35 to $50. I refer to cameras with a stand or tripod. Be enthusiastic, but not a fiend.

CHAPTER XIX.

THE EYE.—SOURCES OF LIGHT.

Describe the optical apparatus of the eye.

The eyeball measures about 1 in. transversely and .96 in. vertically and antero-posteriorly. The optic nerve emerges from it $\frac{1}{10}$ in. to the nasal side of the median line. It consists of three concentric coats

and of certain fluid and solid media enclosed by them: (1) An external fibrous covering, the sclerotic and cornea. They are segments of two spheres: the cornea is anterior, transparent, prominent, and $\frac{1}{6}$ as large as the posterior, which is opaque and has a large radius of curvature. (2) A middle vascular, pigmented, and partly muscular coat, the choroid and iris. (3) An internal nervous stratum, the retina. A fourth may be mentioned internal to these, the hyaloid membrane, which surrounds the vitreous humor.

The refracting media are four: the cornea, the aqueous humor, the crystalline lens, the vitreous body, from before backward.

The iris is an annular diaphragm placed in front of the lens, like a photographer's "stop." It is self-regulating, having control over the quantity of light admitted, and correcting spherical aberration. Its aperture varies from $\frac{1}{20}$ to $\frac{1}{3}$ in. in diameter.

The choroid contains black pigment, like the inside of a camera, and absorbs all rays not intended to co-operate in vision. If this pigment is not present, it is usually lacking in other parts of the body, constituting an *albino.* Here the eyelids are constantly blinking in the endeavor to replace the protection of the pigment.

The back screen of the eye is the retina on which images are made and thence conveyed as sensations to the brain. The essential parts are the rods and cones situated near the external surface of the retina, and most sensitive in the *fovea centralis*, which depression is in the centre of the *yellow spot* in the direct axis of vision. The *blind spot* is where the optic nerve emerges.

The crystalline lens is doubly convex, being more so posteriorly, and is made up of concentric layers of different refractive powers. It is much more refractive than any artificial lens could be.

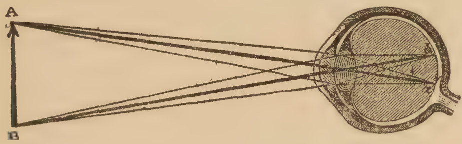
Show the path of rays in the eye.

The rays are refracted at the cornea, both by its density and convexity. The aqueous and vitreous humors have but little more refractive power than water, and are useful to preserve the shape of the eyeball. The lens need alone be considered (Fig. 91). First draw the secondary axes. The rays from A meet their secondary axis at a and the image of B is at b, thus giving a *curved inverted* image on the retina.

The image formed by a convex lens is always curved, and in order

to be distinct at the edges should be received on a curved screen. It is distorted on a flat one, as in the camera. The image is inverted, as can be actually seen in an eye removed from a white rabbit or albino. There are many theories to explain why it is we do not see inverted images of objects. The chief difficulty in explanation seems

FIG. 91.



to have arisen from the conception that the mind or brain is something behind the eye, and looking into it and seeing the image; whereas the image simply causes a stimulation of the optic nerve, which produces some molecular change in some part of the brain. The brain is only conscious of this change, and not of the image nor of its relative position. By sense of touch the mind learns from the first to associate these retinal sensations with a correct position of the object.

How is accommodation effected?

Accommodation means the changes which occur in the eye to fit it for seeing objects at different distances. In the camera we had a fixed lens and a movable screen; here we have a fixed screen and a movable lens.

The crystalline lens varies its refractive powers by changing its convexity. When completely at rest it is adapted for seeing long distances, and we experience no effort. In attempting to see a near object we experience a muscular effort. The ciliary muscle pulls forward the choroid coat, to which is attached the suspensory ligament of the lens. Usually this ligament is tense and compresses the anterior surface of the lens and flattens it. When it is relaxed by the ciliary muscle the lens bulges or becomes more convex by its own elasticity. If this elasticity is lost, then there is no accommodation for near objects.

What are the defects of accommodation, and how are they corrected?

Fig. 92 shows the lens focusing parallel rays upon the retina. An eye that does this is a normal or *emmetropic* eye.

FIGS. 92, 93, 94.

92

93

94

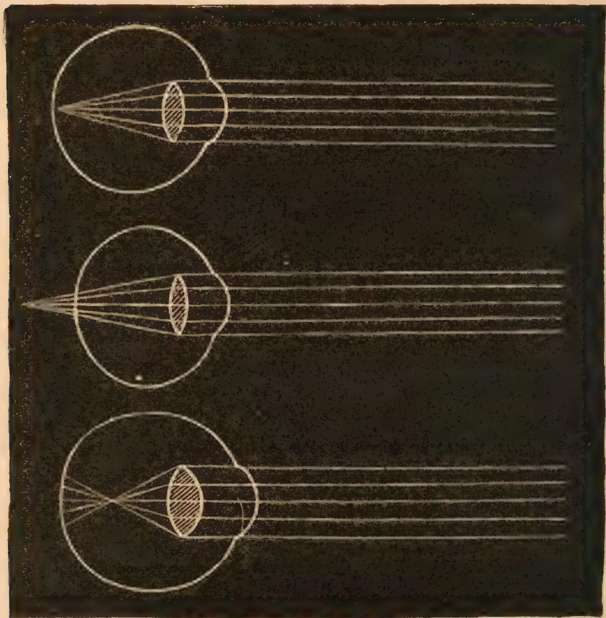


Fig. 93 represents a case of *hypermetropia*, a condition often occurring in old people, where it is called *presbyopia*. The eye is too short and the lens is too flat, and the focus falls behind the retina. It is *far sight;* only distant objects can be seen well, and near ones hardly at all. The remedy is to add another lens to help the crystalline—viz. wear double convex or plano-convex glasses.

Fig. 94 is *myopia* or *short sight*. The eye is too long and the lens too convex, so the focus falls short of the retina. Divergent rays from a near object will fall on the retina. The remedy is to wear

double concave or plano-concave glasses, which diverge the rays so that they do not come to a focus too soon.

The little numbers engraved on glasses express their focal length in inches. The normal eye has a focal length of 10 to 12 in.

Astigmatism is a defect due to greater curvature of the eye in one meridian than in others; it is generally seated in the cornea. Vertical and horizontal lines crossing each other cannot both be focused at once. The remedy is the use of cylindrical glasses—*i. e.* curved in only one direction.

Spherical aberration is corrected by the iris. *Chromatic aberration* is present to a slight extent.

Is there a persistence of visual impressions on the retina?

This persistence is noted when we rapidly swing a live coal: it appears like a circle of fire. The individual teeth of a rapidly-moving saw cannot be seen. If in a dark night a moving railroad train be illuminated by a flash of lightning, it appears at a standstill, for there was not time for the object to assume two different positions during the flash. The length of time for the persistence of an impression is variously stated as from $\frac{1}{30}$ to $\frac{1}{2}$ sec. The zoëtrope, or wheel of life, and other apparatus are founded on this principle.

What is color blindness or achromatopsy?

This is an inability to distinguish certain colors. It is also called Daltonism. This is of the utmost importance to railroad employés and a variety of public servants. The defect is found in about one out of twenty, is more common in men, is congenital, and seems to be hereditary.

The most common kind is red blindness, where there is a difficulty in distinguishing red from green. Cherries and the leaves of the tree have nearly the same hue, and the fruit is distinguished more by its form than by its color. The explanation is that the elements of the retina which receive the impressions of red are absent or poorly developed. There is also a green and a violet blindness.

What is visual purple?

The change effected by light upon the retina may possibly be a chemical one. A certain reddish-purple pigmentation has been found

on the retinal rods of some animals. It is destroyed by the act of seeing, is reproduced, and destroyed again. A solution of it can be obtained from animals killed in the dark. A temporary image may be fixed on the retina by soaking it in alum solution. It is called an *optogram.*

As some animals possess this purple, and other strong-sighted ones do not, the theory is not worth much.

What are the sources of light?

(1) Celestial;
(2) Heat;
(3) Chemical combination;
(4) Electricity;
(5) Meteoric phenomena;
(6) Phosphorescence.

(1) Light comes from the sun and stars: it is a question whether or not the planets emit light or only reflect it, as our moon does.

(2) The great source is heat. When any solid is raised to 1000° F., it begins to emit light, at first of a red color, then cherry or bluish, then white, and then violet. The waves get fast enough to become sensible to the eye, first being seen at $\frac{1}{33000}$ in. wave-length.

(3) Chemical combinations are seen in the gas-jet or candle-flame, which contain solids heated to incandescence.

(4) In electricity the light is due to heat. A poor conductor, whether in a vacuum or not, becomes so hot that it gives (electric) light.

What is phosphorescence and its causes?

Phosphorescence is the property which some substances have of emitting light under certain conditions. They will shine in the dark. In the slow oxidation of phosphorus the light is not due to heat. There are five causes of phosphorescence:

(1) Spontaneous phosphorescence;
(2) Elevation of temperature;
(3) Mechanical effects;
(4) Electricity;
(5) Insolation, exposure to sun.

(1) Sunflowers show light in the dark, and the more if they are shedding pollen. Fungi, decaying wood, meat, and dead fish have this property. The glowworm and firefly seem to have it under the control of the will. The sea is often covered with a phosphorescent light, probably due to the minute animalcules and to a luminous matter emitted by them. An extract has been made from them called noctilucin. It is claimed to be the essence of the phenomena. Powdered oyster-shells, mixed with S or Sb_2S_3 or As_2S_3 and boiled, make a luminous paint, good for a guide to the matchbox.

(2) Certain diamonds, and particularly chlorophane, a kind of fluor-spar, when heated to 300° or 400° C. suddenly emit a greenish-blue light.

(3) Mechanical effects like friction, percussion, or cleavage produce phosphorescence. It occurs when quartz is rubbed together or a lump of sugar broken, and in some processes of crystallization.

(4) By electricity, as seen by the friction of Hg against the sides of the barometric tube.

(5) Some substances exposed to light seem to get a charge of it, and then to give it off gradually. Perhaps it is due to bacteria. The sulphides of calcium and strontium show this, being luminous for thirty hours. Dry paper, silk, sugar, amber, and the teeth show it also.

CHAPTER XX.

DOUBLE REFRACTION.—INTERFERENCE.—POLARIZATION.

What is double refraction?

Certain crystals possess a property by virtue of which a single incident ray in passing through them is divided into two, or is bifurcated, so that an object appears double.

Iceland spar, or calcite, $CaCO_3$, possesses this property most remarkably, and it belongs to crystals not belonging to the cubical or monometric* system. Bodies which crystallize in this system,

* "Monometric" refers to crystals with axes equal or of one kind.

and those which do not crystallize at all, like glass, have no double refraction. It may be imparted to glass by putting it under unequal pressure or by cooling it quickly after being heated, when it is said to be *unannealed.* The explanation of double refraction is that the ether in doubly-refracting bodies is not equally elastic in all directions, so that the vibrations are transmitted with unequal velocities. This hypothesis would seem to be confirmed by the way in which glass acts under pressure.

What is an uniaxial crystal?

In all doubly-refracting crystals there is one direction, sometimes two, through which the incident ray is not bifurcated, and through which a point looked at does not appear double. The line fixing this direction is the optic axis, and if the crystal contains but one, it is *uniaxial;* if two, it is biaxial. In case of Iceland spar the optic axis is a line connecting the opposite obtuse angles of the crystal.

What are the two rays called?

Of the two rays into which the incident one is divided, one is the *ordinary* and the other the *extraordinary* ray, producing also ordinary and extraordinary images. The former follows the laws of single refraction, the latter does not.

In viewing an object beneath a crystal of Iceland spar, and by rotating the crystal, the ordinary image will stay fixed, while the extraordinary one describes a circle around it. A double-image prism is made of calcite and glass.

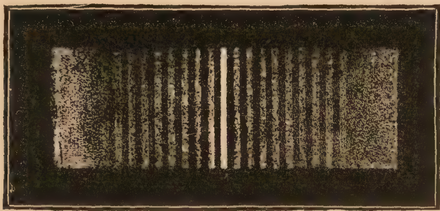
Explain interference of light.

The name *interference* is given to the mutual action which two luminous rays exert upon each other when they meet at a very small angle. In the shutter of a dark room place two very small apertures close together. Close them by red glass for example, so as to get homogeneous light, and let these two luminous cones be received on a screen. Where they overlap will be seen alternate bands of black and red. Close one aperture, and the black bands disappear. In explanation it was once thought that light + light = darkness.

Instead of allowing two pencils of light to fall together upon a screen, one pencil may be reflected upon the screen from the surfaces of two mirrors which are inclined at a very obtuse angle, almost 180°.

In this case also the bands result from the joint action of two pencils. The bands are arranged symmetrically, with the middle one more brilliant than the others, called the central fringe. (Fig. 95). If

FIG. 95.



white light is used, each separate color tends to produce a different set of dark bands. These sets are superimposed, do not coincide, and are illuminated by other colors; so the result is a succession of *colored bands.*

These phenomena of interference prove the truth of the undulatory theory of light, showing an analogy to the nodes and loops formed by sound-waves in air. If the crests correspond, they reinforce each other; if a crest and a trough come together, they destroy each other, and in case of light produce the dark bands.

Another way of interference is seen in thin transparent films of all kinds: white light being used we get colors. In case of soap-bubbles the light which strikes the anterior surface is reflected. Some enters the film and is reflected from its posterior surface, but by traversing the film twice it has lost ground, and on emerging its phases may or may not correspond with those of the other portion. We thus get a play of colors. Press two thick pieces of plate glass together in a vice, and colored rings, called *Newton's rings*, will be seen at the point of greatest pressure. With sunlight the rings are of the different spectral colors. The film here is one of air between the plates. Tarnished glass and mica are iridescent from interference. Oil on water, the metallic oxide on steel, the colors in cracks in ice and glass, the changeable colors on feathers or insects' wings, are all due to thin films.

The relative positions of the bright and dark bands furnish a means for calculating the wave-length of any particular color.

A third way of producing interference is by *diffraction* and *gratings.* The three ways are—

(1) By two mirrors inclined at a large angle;
(2) By films;
(3) By diffraction.

What is diffraction?

Diffraction is the modification which light undergoes when it passes the edge of a body. The luminous rays appear to become bent and penetrate the shadows.

Let monochromatic light in passing an aperture cross a razor edge. One part of the luminous cone is intercepted. On the screen receiving the light a faint light is seen in the geometrical shadow, and above this, where we would expect uniform light, is a series of alternate dark and light bands or fringes. When we watch waves of water strike an obstacle, little secondary waves are formed, radiating from it and winding around behind it. So we may imagine secondary waves of light are generated at the edges of obstacles, and the bending behind is diffraction. Where the original primary waves meet these secondary ones, lights or shadows are produced according as two crests meet or a crest and a trough. White light will give a series of colored bands; any single light (monochromatic) gives light and dark bands.

What are gratings and their effects?

When red light passes through a single slit in an opaque body, a bright band of red light is seen on the screen, and on either side, diminishing in intensity, are other bright bands, separated by darkness. These marked effects are produced by arranging a series of fine wires parallel to each other, or by careful rulings on glass or nickel, the latter reflecting the light. These are called gratings, and may be reproduced by photography. Prof. Rowland of Baltimore has ruled 43,000 lines to the inch. Best results are obtained from gratings ruled on spherical instead of on plane surfaces.

When white light is used with these gratings, a white band is seen on the centre of the screen, and on either side of it an isolated spectrum with the violet edges inward. Next to this, and separated by a dark interval, is another spectrum, somewhat broader and fainter,

and then follow others, which become indistinct and overlap each other. These are all symmetrical with reference to the central band.

Such spectra are called *interference* or *diffraction* spectra, and for scientific purposes are preferable to prismatic spectra, though only one-tenth as bright.

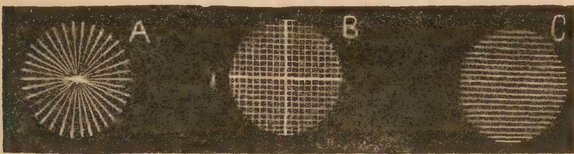
The colors are here uniformly distributed according to their wave-lengths. In the prismatic spectra the red rays were concentrated and the violet ones dispersed.

Diffraction spectra also give the largest number of dark lines, and in their exact relative positions.

What is polarized light?

Polarized light is light vibrating in one plane. Ordinary light vibrates in every plane, and the cross-section of a ray might be represented by A of Fig. 96. For convenience, any motion may be con-

FIG. 96.



sidered as produced by two forces at right angles to each other; so ordinary light may be regarded as vibrating in two sets of planes, as in B, and when it is polarized it vibrates in only one of these planes, as in C.

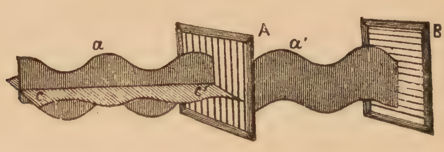
What are the ways by which light may be polarized?

(1) By absorption, tourmaline crystals;
(2) By reflection;
(3) By single refraction;
(4) By double refraction.

(1) Tourmaline has the property of absorbing or of being opaque to all the planes but one. Cut two slices of this mineral in planes parallel with the long axis; when they are similarly placed an object can be seen through them both. But if one tourmaline be rotated, the object gets dimmer, and when the rotating slice is at right angles to the first, it disappears. At each quarter revolution it disappears and is restored. So it seems that light which has passed one trans-

parent tourmaline differs so much from ordinary light that a second similar piece acts as an opaque body. The action may be illustrated by Fig. 97. The first set of vertical rods will allow all vertical planes

FIG. 97.



to pass, but stops those that are at right angles to these rods. Any plane that has passed one set will readily pass another similarly placed. But if grating B is turned so its rods are at right angles to the first, the plane that has passed A will be stopped by this second grating. Light having passed A is polarized, and the first piece of tourmaline is called the *polarizer*, and the second is the *analyzer*. To the eye there is no difference between common and polarized light.

(2) *Polarization by Reflection.*—When a ray of light falls on a polished glass surface inclined to it at an angle of 35° 25′, it is reflected, and the reflected ray is polarized. To see that it is polarized, let the reflected ray be received on a second unsilvered surface, also inclined at the same angle and called the analyzer. This second surface will reflect the polarized ray if it is parallel to the first surface. If not parallel, no light is reflected; so these reflecting surfaces act much like the tourmaline crystals.

What is the polarizing angle?

The polarizing angle of a substance is the angle which the incident ray must make with the perpendicular to a plane polished surface in order that the polarization be complete. The angle of inclination for glass was 35° 25′; so its polarizing angle would be the complement of this—viz. 54° 35′. If the first mirror be inclined at any other angle, the light will not be wholly polarized, but would be partly reflected from the second mirror in all positions.

The polarizing angle for water is 52° 45′, for quartz 57° 32′, for diamond 68°, for obsidian, a kind of volcanic glass, 56° 30′.

The light reflected from water surfaces, from slate roofs, from pol-

ished tables, is all more or less polarized. In the earlier and later parts of the day the light of the atmosphere is polarized. An incident ray meeting a glass surface is partly reflected and partly refracted. It will be found that the reflected polarized ray is always at right angles to the refracted ray.

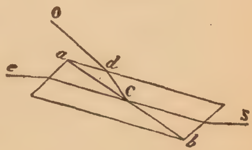
(3) *Polarization by Single Refraction.*—If an unpolarized ray falls upon a glass plate at the polarizing angle, one part is reflected and partly polarized, and the other part is refracted through the glass and also partly polarized. If this feebly polarized ray be passed through a second plate parallel to the first, the effect is more marked, and tolerably complete if ten or twelve plates are used. A bundle of such thin plates fitted in a tube may be used for examining or producing polarized lights. Such plates are used with the magic lantern.

(4) *Polarization of Double Refraction.*—When a ray of light passes through a crystal of Iceland spar, we have seen that it becomes divided into two rays of *equal intensity*, both of which are found to be polarized and in planes at right angles to each other. Now, if either the ordinary or extraordinary ray be transmitted through a second crystal, a second ordinary and a second extraordinary ray will result, but of *unequal intensities.* If the second crystal is rotated, so that the two are similarly placed, then in one case the second extraordinary ray disappears, and the second ordinary ray is at its greatest intensity. Turn the second crystal at right angles to the first and the reverse takes place. The second crystal acts as an analyzer.

Describe Nicol's prism.

A rhomb of calcite about 1 in. high and $\frac{1}{3}$ in. broad is bisected in the plane of its optic axis—*i. e.* through the opposite obtuse angles. The halves are glued together again in the same order by Canada balsam.

FIG. 98.



When ray S C enters the prism (Fig. 98) the extraordinary ray passes through it in C *e*, but the ordinary ray strikes the balsam surface *a b* at a greater angle than its critical angle, and passes wholly out of the prism in C *d* O, and is thus

gotten rid of. This is one of the most valuable means of polarizing light, and is used in most polarizing apparatus. It gives perfectly colorless light, it polarizes completely, and transmits only one beam.

Foucault replaced the layer of Canada balsam by one of air, and his prisms are just as good and cheaper than Nicol's. Either variety may be used as a polarizer or an analyzer.

What are some of the polarizing instruments?

Every instrument of this kind consists of two parts—one to polarize the light, and the other to ascertain if it is polarized—the polarizer and the analyzer. Norremberg's apparatus involves the principle of reflection by two mirrors.

A simple polariscope can be made of a glass plate for a polarizer and a Nicol's prism for an analyzer. The tourmaline pincette is used by mineralogists for examining certain crystals and kinds of mica. The substance examined is placed between the two disks of tourmaline.

What is the result of interference of polarized light?

When polarized rays meet they cause the results of interference as does ordinary light. If the two rays are polarized in the same plane, they produce the very same fringes that common light does. Place a thin film of gypsum or of mica between the polarizer and analyzer, as in a tourmaline pincette. Rotate the analyzer, and at a certain point there is a beautiful display of colors; at another point they will fade away; and at still another will appear colors complementary to the first. This is due to the interference of polarized light in passing through the thin substance which takes the place of the layer of air when Newton's rings are formed, only it must be thicker than that layer of air. Compressed or unannealed glass also yields colors with polarized light.

Describe rotatory polarization.

Polarization may be elliptical, circular, or rotatory. Let a ray of monochromatic light be polarized; turn the analyzer, say, a Nicol's prism, so that the ray does not pass. Take a thin section of quartz and place it between the analyzer and polarizer, and the light will now be found to pass; that is, we have to turn the analyzer through a certain angle to let the light through. This angle expresses the

rotatory power of the substance. With some specimens of quartz the plane of polarization is turned to the right, and with some to the left.

A magnet twists the plane of polarized light. Many liquids and solutions exhibit this property, and the deviation can reveal differences in the composition of bodies where none are shown by chemical analysis.

Biot has a polariscope for measuring the amount of rotation in liquids. Soleil's saccharimeter is used for analyzing sugars, and consists of a tube containing the liquid between a polarizer and an analyzer. Diabetic urine may be thus examined and the amount of sugar determined.

Rays of heat also become polarized, and Nicol's prism may be used for heat as well as for light.

What are Hertz's experiments?

In 1888, Hertz proved the existence of ether waves and measured their velocity. To understand his method, it must be remembered that a spark discharge is oscillatory. There is not a rush of + and − electricities from opposite sides, stopping dead when they meet, but a swinging to and fro many millions times per second. Hertz's *vibrator* consists of two metal rods between whose terminals is a spark-gap; each is provided with a sphere for condensation.

The system is charged by an induction coil, and sparks are produced with great rapidity, sending ether waves into space.

To detect these waves he employed the principle of resonance, using for a *resonator* an open wire ring with terminals and a small spark-gap. When the ring and vibrator were held in the same horizontal plane, sparks would cross the gap in the ring or could be taken between any two metallic objects, as keys or coins. By using sheets of tin-foil upon two rods as a receiver, sparks were obtained 30 metres from the vibrator. These waves could also be reflected to a focus or refracted.

To get the velocity he used a metallic reflector, so the waves turned back on themselves, producing maximum and minimum disturbances corresponding to loops and nodes. This gave the wave-length, from which the velocity was found to be almost identical to that of light.

These facts seem to prove without a doubt that light is an electrical phenomenon, and that optics is a department of electrics.

BOOK IV.

ON SOUND.

CHAPTER XXI.

PROPAGATION AND VELOCITY OF SOUND.—MEASUREMENT OF VIBRATIONS.

What is the difference between noise, sound, and music?

The study of sound and of vibrations of elastic bodies is called the science of *acoustics*. If a body strikes the air a single blow, as the discharge of a cannon, the ear receives a single shock, called a *noise*. If separate noises are repeated so rapidly that the ear cannot distinguish the separate shocks, it perceives a continuous *sound*. Should such continuous sound be pleasing, it is called a *musical sound:* the essentials are regularity and simplicity.

What is the cause of sound?

Sound results from rapid oscillations imparted to the molecules of elastic bodies. Such bodies tend to regain their first position of equilibrium, and reach it after rapid vibrations.

The body which produces sound is a *sonorous* body. In England and Germany a vibration comprises a motion to *and* fro; in France it is to *or* fro, a movement in only one direction.

How are sounds propagated?

The vibrations of elastic bodies are transmitted to some medium and the vibrations of the medium affect the ear and produce the sensation of sound. This medium is usually air, but all gases, vapors, liquids, and solids transmit sound.

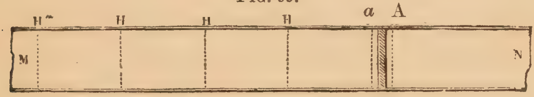
Sound is therefore imperceptible in a vacuum; the vibrations may be there, but there is no vibrating medium between the sonorous body and our ear.

Solids are good conductors of sound. A pin-scratch on one end of a log can be heard at the other end. The tramping of distant horses can be heard by an ear applied to the ground.

Sounds in air are propagated *in waves.* Take a spiral spring with one end fixed, and rake its side by any instrument. Some of the turns of wire will be seen to be closer than others, a condensation, while some turns are separated, a rarefaction. Something similar occurs in air.

In Fig. 99, P is a piston rapidly oscillating from A to a. It com-

FIG. 99.



presses the air in tube M N, when P goes from A to a, but not at once throughout its whole length; only for a length, as a H; and this is the condensed wave. Let other lengths be taken equal to a H, and when the first layer of wave a H comes to rest, its motion is communicated to the first layer of wave H H′, and so on, each part of the condensed wave having successively the same degree of velocity and condensation. When the piston returns from a to A, a vacuum is produced behind it, causing a rarefaction of the layers of air; so expanded waves are produced of the same length as the condensed ones, and the corresponding layers of the two possess equal and contrary velocities.

The whole of a condensed and an expanded wave is an *undulation.* The length of an undulation is the space which sound traverses during one complete vibration of the sonorous body. The length is less as the vibrations become more rapid.

Two particles are said to be in the same *phase* when they move with equal velocities in the same direction. It will be seen that two particles are in the same phase if separated by a whole undulation; in opposite phases if separated by half an undulation. Condensation is greatest in the middle of a condensed wave, and rarefaction greatest in the middle of an expanded wave.

If the sound-waves be not enclosed, a series of spherical waves, alternately condensed and rarefied, is produced around each sonorous

centre. The radii of these concentric spheres gradually increase; the amplitude of vibration lessens, and the intensity of sound diminishes.

These spherical waves of course are the most usual ones for propagation of sound.

What are the causes which influence the intensity of sound?

(1) The intensity is inversely as the square of the distance. Double the distance, one-fourth the intensity.

(2) The intensity increases with the *amplitude of vibrations.* Amplitude means the greatest distance of any point in a wave from the axis. Wave-length is the distance between two crests.

(3) The intensity of sound depends on the density of the medium in which it is produced. It is *nil* in a vacuum, and feeble in H gas. On high mountains the discharge of a gun produces only a feeble report. The ticking of a watch in water is heard at a distance of 23 feet, in air at 10 feet.

(4) The intensity is modified by the motion of the atmosphere and direction of the wind.

(5) Sound is strengthened by the neighborhood of a sonorous body. Stringed instruments are provided with sounding boxes; the box and its contained air vibrate in unison with the string. Resonant brass vessels were placed in the ancient theatres to strengthen the voices of the actors. A "sounding-board" over the pulpits in old churches is for the same purpose.

The first law is not true for sounds transmitted in tubes. The voice loses little of its intensity in a long tube, provided its diameter be not too large or its sides too rough. "Speaking-tubes" are an illustration.

What is the velocity of sound in air?

This was determined in 1823 by firing cannon simultaneously from two hills near Amsterdam and noting the time between seeing the flash and hearing the sound. The time required for light to traverse a short distance is regarded as inappreciable. The velocity of sound at 0° C. may be taken at 1093 ft., or 333 metres, per sec., a little less than that of a rifle-ball. It increases with the T. about 2 ft. or .6 metre for every 1° C. At 60° F. it is 1125 ft. per sec. If 5

seconds elapse between the flash of lightning and hearing the thunder, that stroke was about 1 mile distant.

The more intense the sound, the more rapid its transmission. During artillery practice the report of a gun may be heard before the order given to fire by the officer. Density retards and elasticity increases the velocity.

What is the velocity of sound in gases?

The velocity in gases is represented by the formula $v = \sqrt{\frac{e}{d}}$; *i. e.* is directly as the square root of the elasticity and indirectly as the square root of the density. In Cl gas it is 677 ft. per sec., in H gas 4163 ft. per sec.

Doppler's principle is that when a sounding body approaches the ear the tone perceived is somewhat higher than the true one; if the sound recedes, it is lower. As the sound approaches the ear receives more waves per second and the sound is higher pitched, and *vice versâ.*

What is the velocity of sound in liquids?

For water this was determined in Lake Geneva. At one boat was an immersed bell and a flash simultaneous with its stroke; at a distant boat was an immersed ear-trumpet. The velocity was found to be 4708 ft. per sec. at 8° C., four times that in air. Aqueous vapor is an obstacle to sound, but not white fog, hail, or snow.

What is the velocity of sound in solids?

As the elasticity of solids in general is greater compared with their density than that of liquids or gases, their propagation of sound is more rapid. Two distinct reports of the rock-blast may be heard, one transmitted through the air, and one through the earth. The latter is heard first. For oak wood the rapidity is 12,622 ft. per sec.; for steel it is 16,498 ft. It is three times less if across the fibre of wood. In water the rapidity is four times that of air, in Cu eleven, in glass sixteen, in wood along the fibre 10 to 15.

How is sound reflected?

As long as sound-waves are not obstructed they are propagated in concentric spheres, but when they meet an obstacle, they return

upon themselves, forming new concentric waves, which seem to emanate from a second centre on the other side of the obstacle. The two laws for the reflection of sound are identical with those for light and radiant heat.

What are echoes, multiple echoes, and resonances?

An *echo* is the repetition of a sound in air, caused by its reflection from some obstacle. For articulate sounds that obstacle should be at least 112.5 feet distant, for not more than five syllables can be heard or pronounced distinctly in one second—$\frac{1}{5}$ sec. for each syllable, in which time sound travels 225 ft. ($1125 \div 5 = 225$). If the reflecting surface be 112.5 ft. distant, the sound in going and returning will traverse the 225 ft., and no two sounds would interfere. If the distance is less than 112.5 ft., the direct and reflected sounds are confounded, resulting in *resonance.* These points are of importance in architecture.

Multiple echoes or reverberations are those which repeat the sound several times; some do so as many as thirty times.

There are acoustic foci, like luminous and calorific foci, and sounds, even a whisper, are heard at such points, and not at intermediate ones. This is the principle of whispering galleries and the "Ear of Dionysius."

Illustrate refraction of sound.

Refraction of sound is a change of direction in passing through media of different densities. Place an ear at the small end of a funnel and listen to a watch 10 or 12 ft. distant. Then introduce a collodion balloon filled with CO_2 gas between the funnel and the watch. The sound is greatly increased. The convex wave-fronts were becoming diffused through wider and wider space, but on meeting the dense gas these fronts became plane fronts, and then emerged as concave fronts, concentrating the sound energy upon the funnel. A balloon filled with H gas would act like a concave lens and dissipate the sound.

The principle of the speaking-trumpet depends upon the consonant vibration of a large mass of air before it begins to be diffused. The ear-trumpet and stethoscope are the reverse, and concentrate the enlarging waves upon the ear. The external ear is hardly a

sound condenser, but some part of its many irregularities will offer a surface perpendicular to some one of the many sound-waves; vibrations will then be transmitted to the internal ear.

How may the number of vibrations be measured?

This can be determined by means of *Savart's toothed wheel* or by the *siren.* A toothed wheel is revolved with such speed that a note is produced by its teeth striking a card, which note is identical with the sound to be tested. The number of turns can be read off on an indicator, and this, multiplied by the number of teeth, gives the total number of vibrations. Divide this by the number of seconds it was revolved to get the vibrations per second.

The name *siren* was given to another apparatus, because it yields sounds under water. Let a fixed brass plate have, say, 18 perforations, which shall be opposite 18 other holes in a movable disk placed upon it. The holes are inclined to each other thus, >, and are not vertically placed. As wind from a bellows strikes the sides of the holes of the movable disk, it begins to rotate, and a series of stoppages and effluxes are produced which make the air vibrate, not the disk. A sound is produced of varying pitch. There are recording dials attached to indicate the number of revolutions. The buzzing and humming of insects is produced by the flapping of their wings, the rapidity of which can be counted by bringing the siren into unison with this sound. A gnat's wing flaps about 1500 times per second. A steam-horn on the siren principle is used as a fog-horn.

What are the limits of perceptible sounds?

There are many discordant results obtained, probably due to the different capacities of different ears. Preyer found that the normal ear could not hear a sound unless it made 16 to 24 single vibrations per second. Below this number the impression of separate beats is produced. The maximum limit of acute sound may be 41,000 vibrations per second, yet many with good ears are deaf to 16,000 or 12,000 per sec. This large number of vibrations affects the ear as though it were pricked by a pin. The above range is about 11 octaves; that of the human voice is 3 or less. The lowest note of a 7½-octave piano makes about 27½ vibrations per sec., and its high-

est note 4224. Some ears cannot hear a bat's cry or the creaking of a cricket. The intensity of the sound increases the limit of audibility.

CHAPTER XXII.

MUSIC AND MUSICAL INSTRUMENTS.—PHONOGRAPH.

What are the properties of musical notes?

The vibrations of musical notes must be continuous, rapid, and regular. They have three leading qualities—*pitch*, *intensity*, and *timbre.* (1) Pitch is determined by the number of vibrations per second. (2) Intensity depends upon the extent or amplitude of vibrations. (3) Timbre, or quality, is that peculiar property which distinguishes a note when sounded on one instrument from the same note when sounded on another. It depends upon the differences of the harmonics which accompany the primary tones.

What are musical intervals?

Suppose a note, C, is produced by a certain number of vibrations per second, and another note, x, by a greater number of vibrations. The interval from C to x is the ratio of their vibrations, obtained by *division*, and not by subtraction. Two or more notes may be separately musical, but not necessarily if sounded together; so we have to inquire what notes are concordant or fit to be sounded together. If notes are separated by an interval of 2 : 1 or 4 : 1, they closely resemble each other. If c has twice as many vibrations as C, the interval 2 : 1 is called an octave.

If three notes, x, y, z, have their vibration numbers correspond to the ratio 4 : 5 : 6, they will be concordant, and constitute an *harmonic triad:* if sounded with a fourth note, the octave of x, it constitutes a *major chord.*

If three notes have the ratio 10 : 12 : 15, the sounds are slightly dissonant, and with the octave to the lower one they constitute a *minor chord.*

How is the musical scale formed?

The series of sounds between C and its octave *c* is called the *dia tonic* scale or *gamut.* These notes are indicated by the letters C, D, E, F, G, A, B, *c*—the octave above by small letters, the one below by large letters with an index. If the vibration number of C be represented by unity, those of the other notes are given in this table:

C	D	E	F	G	A	B	*c*
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
264	297	330	352	396	440	495	528

The intervals between the successive notes will be found to be one of three fractions, $\frac{9}{8}$, $\frac{10}{9}$, or $\frac{16}{15}$: the first two are called a *tone*, and the last a *semitone.* The two tones, however, differ by $\frac{81}{80}$, called a *comma.* A trained ear can readily detect this difference; it cannot determine the number of vibrations corresponding to a given note, but shows great precision in regard to the ratio of vibration numbers.

How is the chromatic scale formed?

Each note may be sharpened or flattened—*i. e.* raised or lowered by an interval of $\frac{25}{24}$. This gives 21 notes between C and *c*, any one of which may be taken as a key-note, and a scale constructed from it. This would be quite unmanageable; so the number of notes has to be reduced by slightly altering their just proportions. This process is called *temperament.*

The octaves are retained pure, and between C and *c*, eleven notes are substituted at equal intervals, each interval being the twelfth root of 2, or 1.059+. The scale of twelve notes thus formed is called the *chromatic* scale.

What is the number of vibrations producing different notes?

An instrument is in tune provided the intervals between its notes are correct. Middle C on the best American pianos has about 270 double vibrations per sec., and on German 264; the French legal standard is 261. Physical apparatus is usually based on 256, as this is a power of 2. (See the above table of vibrations.)

The standard for vibrations is a normal tuning-fork, which always,

with slight variations for T., produces the same number of vibrations per second.

How is wave-length determined?

Sound travels 1125 ft. per sec. If a sounding body only made one vibration per second, its wave-length would be 1125 ft.; if two, its wave-length would be ½ of 1125—*i. e.* wave-length $= \frac{\text{velocity}}{\text{No. of vibrations}}$. The wave-length is inversely as the number of vibrations.

The amplitude of oscillation for high notes is very small—for f^{iv} perhaps not greater than .0000001 mm.

What are overtones and harmonics?

The sounds coming from a string or other body vibrating in parts are called *overtones*. If the vibration number of the overtone is two, three, or four times that of the fundamental, the sound is called a *harmonic*.

When primary C is sounded on most instruments, its octave becomes audible; then the fifth to that octave, then the second octave, then the third and fifth to that octave. These are all harmonics, and may be heard by a little practice.

What is the difference between consonance and resonance?

A vibrating body has the power to cause a body at rest to vibrate in the same period. This is *consonance*. A regiment of soldiers marching in step will set up a dangerous oscillation of a bridge, and it is said that a bridge can be fiddled down if it will vibrate in unison with the violin.

The reinforcement of sound by attaching to a sounding body a sound-board or wooden box containing air is called *resonance*.

How are vocal sounds produced?

Vocal sounds are produced in the larynx by means of the vocal cords. These have different degrees of tension, and the current of air passing between them causes them to vibrate, producing tones.

The tones are higher the more tightly the cords are stretched and the narrower the vocal slit.

The cavities of the mouth, nose, and various sinuses, modified by the tongue, act as a resonator. The wave-length of sounds emitted

by a man's voice in ordinary conversation is about 8 to 12 feet; that of a woman's, 2 to 4 feet. The average compass of the human voice is within 2 octaves. Celebrated singers have had a range of $3\frac{1}{2}$ octaves.

How are sounds perceived?

The chief organ concerned in the perception of sound is a series of fibres called Corti's, which are connected with the auditory nerve. It seems that each one is tuned for a certain note, as if it were a small resonator; one fibre or set of fibres vibrates in unison to this note, and is deaf to all others. There are about 3000 of these fibres, thus allowing nearly 300 to each of the 11 octaves which are within the compass of the ear. In the piano every string has its own hammer, while the ear possesses a single hammer in its three ossicles, which can make every string of the organ of Corti sound separately.

What is interference of sound and beats?

If two waves of sound of the same length proceed in the same direction and coincide in their phases, they strengthen one another. But if their phases differ by a half wave-length, they neutralize each other and silence results. This is interference of sound. If the notes are different and not quite in the same phase, they alternately weaken and strengthen each other, and are said to *beat* with one another. When the crests of two waves correspond, the sound is intensified: a crest and a trough produce silence. If one tuning-fork makes 256 vibrations per sec., and another 255, once during the second there will be a time of maximum intensity and one of minimum intensity. The number of beats is always equal to the difference between the vibrations.

Beats from 10 to 70 per sec. are the source of all discord in music, a maximum of dissonance being at 30. Below 10 or above 70 they are disagreeable, but not discordant. Church bells or vibrating telegraph wires produce beats.

The Vibrations of Strings and Columns of Air.

What are the laws of transverse vibrations of strings?

Stretched strings of catgut or of metal wire vibrate either transversely or longitudinally. The *sonometer*, or monochord, is the in-

strument by which such vibrations may be studied. It consists of a resonating box upon which are placed two bridges. A string or wire fastened at one end and weighted at the other is passed over these. A third, movable, bridge alters the length of the vibrating portion. The laws determined are these:

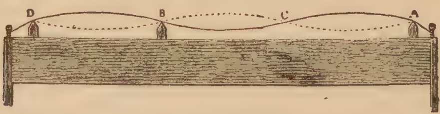
Let N = the number of vibrations per sec.

1. N is inversely as the length, the tension being constant.
2. N is inversely as the diameter of the string.
3. N is directly as the square root of the tension.
4. N is inversely as the square root of the density of the string.

How are nodes and loops formed?

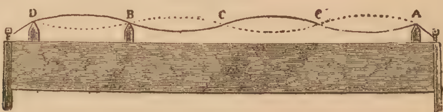
In Fig. 100 let us suppose the string A D to begin vibrating, A and D being fixed, and while vibrating let B be brought to a rest by a

FIG. 100.



stop. Let D B be $\frac{1}{3}$ of A D. All parts of the same string tend to make a vibration in the same time; accordingly, the part between A and B will not perform a single vibration, but will divide in two at C. If D B were $\frac{1}{4}$ of A D, then A B would be subdivided at C and C′ into three vibrating portions, each equal to B D (Fig. 101).

FIG. 101.



The ratio between B D and B A must be that of whole numbers. The points B, C, and C′ are called nodes; the middle point between nodes is a loop or ventral segment.

Little paper riders placed on the string will show these points and be thrown off at the loops. Partial vibrations will be superimposed upon the primary, and overtones are produced.

What is the principle of wind instruments?

Hitherto we have only noted air as a vehicle for the transmission of sound. In wind instruments the enclosed column of air is the sounding body. The substance of the tube has no influence on the fundamental note, but different materials give different harmonics, and thereby impart a different quality.

Wind instruments are divided into *mouth* and *reed* instruments. In the former the parts of the mouth-piece are fixed. Fig. 103 represents the mouth-piece of an organ-pipe, and Fig. 102 that of a whistle. Air enters the tube through the aperture *i b*. *b* and *o* are lips, the upper of which is bevelled. When a rapid current of air enters *i b*, it strikes against *b* and issues from *b o* in an intermittent manner. These pulsations are transmitted to the air in the pipe, which air vibrates and sound is the result. The number of vibrations depends upon the dimensions of the pipe and the velocity of the air-current.

FIG. 102.

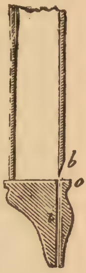


FIG. 103.

In the reed instrument a simple elastic tongue sets the air in vibration, the tongue being moved by the entering current of air. The reed may be *free*, vibrating between the edges of the aperture, or *striking*, in which case the tongue is larger than the orifice.

What are some of the differences between closed and open organ-pipes?

In case of an open pipe, if the fundamental be represented by 1, we can obtain the notes 2, 3, 4, 5, 6, etc., *all* the harmonics of the primary, by increasing the force of the current of air. By a closed pipe we can obtain the notes 3, 5, 7, etc., the *uneven* harmonics.

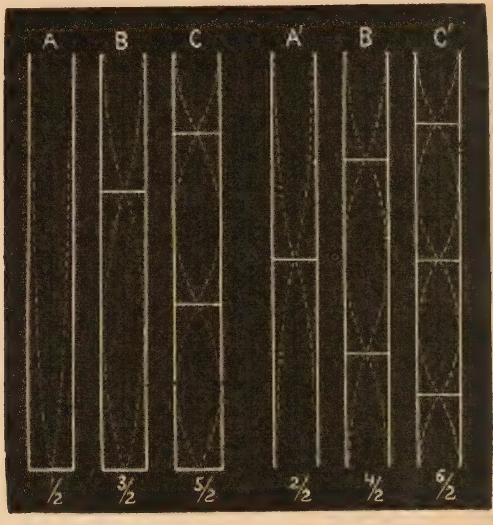
The vibrations of the air column take place in a direction parallel to the axis of the pipe: nodes and loops are produced. Here a node means a section where there are rapid changes of density in the air.

In the loops the particles of air have the greatest amplitudes and no change in density.

(1) *Closed Pipe.*—The bottom is always a node, for that layer of

air is at rest; at the mouth-piece is a loop, the vibration being at its maximum. When the pipe yields its fundamental (Fig. 104), A,

FIG. 104.



the distance from one end to the other is a ½ wave-length. If the current of air be forced, the column divides itself into three equal parts, 1½ wave-lengths, B. This sound is the first harmonic. When the second harmonic is produced the column has five equal parts or $\frac{5}{2}$ wave-lengths, C. The ratio is 1 : 3 : 5.

(2) *Open Pipes.*—There must always be a loop at each end. The fundamental will divide the column into two equal parts, A′. With the first harmonic there will be a loop at either end, and one in the middle, or four equal parts, B′. The second harmonic will divide the column into six equal parts, C′. The ratio is 1 : 2 : 3. In both stopped and open pipes the number of vibrations is inversely as the length of the pipe.

In comparing A and A′, it will be seen that the fundamental wave-length of the closed pipe is twice that of the open one. Long wave-lengths go with fewer vibrations: pitch depends on the num-

ber of vibrations; therefore a closed pipe is an octave *lower* than an open one of the same length.

Ganot makes a contrary statement.

Describe the chemical harmonicon.

The air in an open tube may be made to vibrate by means of a luminous jet of H or of coal gas. The sounds are supposed to be produced by exceedingly rapid explosions of the periodic combination of the O_2 in air with the jet of H. Louder effects are produced by coal gas, the note depending on the size of the flame and length of the tube. If the voice or siren be raised to this note, the flame is agitated until the two sounds are of the same pitch. This is the optical expression of beats. Take a metal tube 4 cm. in diameter and 20 cm. long; close the bottom with wire gauze, and hold it vertically over a Bunsen burner. Light the gas inside the tube, and a noise is produced almost as loud as a locomotive whistle.

How do rods, plates, and membranes vibrate?

Rods vibrate in two ways—longitudinally and transversely. The tuning-fork or music-box are examples of transverse vibrations of rods. Vibrating *plates* contain nodal lines, which vary in number and position according to the form of the plates, their elasticity, etc. These lines are very symmetrical, and may be formed by touching different points. Gongs and cymbals are examples of vibrating plates.

Bells do not vibrate as a whole, but in equal parts, separated by nodal lines.

Vibrations of *membranes* are illustrated in the drum, the contained air also vibrating.

How may vibrations be studied graphically?

Lissajous' method depends upon the persistence of visual sensations upon the retina. A small mirror is fixed on a vibrating body, and imparts to a reflected luminous ray a vibratory motion similar to its own. The image of a dot of light elongates or becomes curved, and a great variety of symmetrical figures are formed by combining two vibratory motions.

Another way is by the *phonautograph*, which is an ellipsoidal barrel with one end open, and the other closed by a membrane car-

rying a bristle. The vibrations of the membrane are transferred by the bristle to blackened paper revolving in front of it.

Thirdly by *König's manometric flames.* The motion of sound waves is transmitted to gas flames, which by their pulsations show the nature of the sounds. These flames are received on a mirror with four faces, which may be rotated, and produces a band of light with serrated edges.

Is there any attraction or repulsion in acoustics?

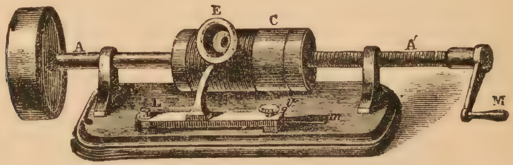
It has been observed that a sounding body exercises an action upon a body in its neighborhood, sometimes of attraction and sometimes of repulsion. The vibrations of a medium will attract bodies which are specifically heavier than itself, and repel those which are lighter. Two suspended vibrating tuning-forks move toward each other.

These phenomena are not due to aspirating action of air nor heating effects. Their further elucidation may help solve the problem of attraction in general.

Describe the phonograph.

In 1877, Edison devised the phonograph for recording and reproducing sound. It consists of a cylinder C mounted on a horizontal axis A A′; which can be rotated beneath a mouth-piece E. (Fig. 105).

FIG. 105.



On the cylindrical surface is cut a shallow spiral groove, like the thread of a screw. A small style projects from the under surface of a thin disk which closes one end of the mouth-piece and stands directly over the thread. The axis also has a screw thread, so that the cylinder advances as it rotates, and allows the groove to keep constantly under the style. Over the cylinder is stretched a sheet of tin-foil, which is indented when the membrane and its style vibrate.

Some of these indentations are visible to the eye, and others require a microscope. After the sounds are recorded, if the indented tin-foil be again passed beneath the style, it will play up and down, and the membrane will vibrate just as it did when it produced the indentations. These vibrations are communicated to the air, and the original sounds are reproduced. Speech, music or messages may be thus stored up indefinitely. The business-man or author may dictate his letters or thoughts to this machine, and have the typewriter transcribe them later. By suitable clockwork and reproducers speeches, plays, music, etc. become audible to a large assembly or to the individual at the "slot machine." It is useful in medical teaching for comparison of sounds.

The graphophone, invented by Tainter and Bell, has a cylinder covered with wax, and the style is a minute chisel. It yields excellent results, and the same record will reproduce the original hundreds of times.

What is Edison's kinetograph?

Recently Edison has combined under the above name the phonograph and photographic camera. By an electric attachment he takes 46 pictures per sec. on a gelatin film, or 82,800 in half an hour, so that motion—*e. g.* on the stage—is reproduced as real motion and not a series of jerks. This and the phonograph work together, and take down an opera with every move of the actors and every sound.

The negatives are developed, and when projected on a screen, keeping time with the reproduction of sound from the phonograph, you have a continuous life-size picture of what went on, and hear simultaneously every voice. The practical utility of this machine remains to be seen.

BOOK V.

ON MAGNETISM AND ELECTRICITY.

CHAPTER XXIII.

PROPERTIES AND USES OF MAGNETS.—LAWS OF ACTION.

What are magnets and their varieties?

Electricity is of three kinds—magnetism, statical, and dynamical: it will be studied in this order.

Magnesia was a small country in Asia Minor, and is now noted for giving its name to three things: to magnesia alba, or carbonate of Mg; to magnesia nigra, or peroxide of manganese (MnO_2), and to substances called magnets.

Magnets are substances which have the property of attracting iron and the like. There are four kinds:

(1) Natural;
(2) Artificial,
  (*a*) permanent,
  (*b*) temporary;
(3) Magnets by induction;
(4) Magnets by electricity.

(1) A certain ore of iron, the *magnetic oxide*, Fe_3O_4 (from FeO + Fe_2O_3), constitutes the *natural magnets*. It is called lodestone, from its use as a leading stone. Only loose fragments exhibit this property, and not the mass. It attracts other iron, and when suspended directs itself north and south. These are permanent magnets.

(2) *Artificial magnets* are usually made from steel or soft iron.

The former are permanent, and the latter temporary. The quality of steel by which it first resists the power of magnets and the escape of magnetism when once acquired is called its *coercive force.* The harder the steel, the greater its coercive force; soft iron has least.

(3) The action by which a magnet can develop magnetism in iron is called magnetic *influence* or *induction*, and may take place without actual contact of the two.

(4) Electro-magnets are made by circulating an electric current about a core of soft iron. They are temporary magnets.

What are the properties of magnets?

1. Attraction;
2. Polarity;
3. Magnetic rupture;
4. Magnetic induction;
5. Electricity.

What are poles and the neutral line and axis?

The force of attraction varies in different parts of a bar magnet. This may be seen by placing it in iron filings, when the ends will become covered with feathery tufts, with none in the middle. The ends are the *poles*, and the mid-point the *neutral line.* Sometimes *consequent* poles are produced in artificial magnets between the extreme points. This is due to improper magnetization or to irregularities in the metal. The *axis* of a magnet is the shortest line joining its two poles; in the horseshoe magnet it is in the direction of the armature.

When a magnet is freely suspended, it sets with one end, the north pole, pointed toward the north and the south pole toward the south. In France and China the reverse terms are used. The north pole is often called the *red, the* +, or the *marked* end of the needle, and the other is the *blue, the* —, or the *unmarked* end.

What is the law of magnets?

Poles of the same name repel, and poles of the contrary name attract one another. Like poles repel, unlike attract.

The attraction which a magnet exerts upon iron is reciprocal; this is the general principle of all attractions. Place one bar-magnet

upon another, so that poles of contrary names are opposite, and they will neutralize each other and not support a weight.

What are the theories of magnetism?

(1) Poisson's *two-fluid* theory.
(2) Weber's theory of *magnetic polarization.*
(3) Ampère's *electrical* theory.

(1) The presence of two fluids is assumed, each acting repulsively on itself, but attracting the other. Magnetization separates them, and brings the north fluid to one end of the molecule and south fluid to the other end.

(2) Weber supposes the molecules of a magnetic substance are always magnets, but their magnetic axes are turned in every direction. Magnetization rotates them to the same direction.

(3) Ampère assumes little electrical currents to pass around every molecule. In an unmagnetized bar they lie in all possible planes and neutralize each other. When a magnet or a current of electricity is brought near, the effect of induction is to bring these little currents into parallel planes and in the same direction. (Fig. 139.)

What is meant by magnetic rupture?

The Ampèrian currents are present in all parts of the bar, and not alone at the ends. If a magnetized knitting-needle be broken in the middle—*i. e.* in the neutral line—we shall find two poles and a neutral line for each half. If these halves are in turn broken, the same will be true for them, and so on indefinitely. In fact, each molecule is a magnet.

What is magnetic induction?

When a magnetic substance is brought near to or placed in contact with a magnet, its Ampèrian currents, running in every direction, are made parallel and in the same direction, and two poles and a neutral line are established. If a small cylinder of soft iron be in contact with one pole of a magnet, this little cylinder can support a second one, and so on to as many as seven or eight. Each cylinder is a magnet temporarily. If the first cylinder be at the north pole of the magnet, its end in contact will be the south pole, and its far end the north pole, according to the law. If the first cylinder be removed, the others drop and have no trace of magnetism left. In case of iron

filings which collect on a magnetic pole, each particle is transformed into a magnet, producing filaments of filings, their free ends repelling each other.

What is the difference between a magnet and a magnetic substance?

A magnet exhibits polarity and attraction for the magnetic substance. Magnetic substances are attracted by the magnet—have no polarity and no action on each other.

Iron leads the list of magnetic substances, metallic iron and Fe_3O_4; then come nickel, cobalt, chromium, manganese, and cerium.

How are substances classed according to their behavior toward magnets?

(1) Magnetic substances attracted, paramagnetic;
(2) Diamagnetic substances repelled;
(3) Neutral.

(1) Magnetic substances place themselves *axially* between the poles of an electro—or horseshoe magnet. Magnetic liquids in a watch-glass between the poles become heaped up at the poles and depressed in the centre. The behavior of gases can be seen by inflating a soap-bubble with the gas and noting the direction of distension. O_2 is magnetic.

(2) Diamagnetic substances are repelled and take up an *equatorial* position between the poles—*i. e.* their longest axis is at right angles to the axis of the magnet. Such are Bi, Sb, P, Ag, Cu, alcohol, water, and most gases, N and CO_2.

(3) Very few substances exhibit no action to magnetic influence, as paper, wood, glass; nearly all are either attracted or repelled.

Nothing is opaque to magnetism. It changes the length, but not the volume, of the bar magnetized.

What may be said of terrestrial magnetism?

The earth may be compared to a great magnet, for a magnetized needle on any part of the globe ultimately sets in a direction more or less north and south. The cause is unknown; perhaps thermo-electric currents run around the earth from east to west, their source being the sun.

Following out the law that unlike poles attract, we ought to say that the south pole of the needle points to the north magnetic pole of the earth: this distinction is not usually made in this country. The magnetic poles and equator do not correspond with the geographical poles and equator.

What are the magnetic elements?

In order to determine a full knowledge of the earth's magnetism at any place, three essentials or elements are necessary:

(1) Declination or Variation;
(2) Inclination;
(3) Intensity, horizontal and vertical.

(1) The magnetic meridian of a place does not usually coincide with the geographical meridian. The angle which the direction of the needle makes with the geographical meridian is called the *declination.* It is a movement *from* the true north or south, and may be either east or west. At present it is west in Europe and Africa, and east in Asia and most of North America.

What are the variations in declination?

1. Regular:
   (*a*) secular,
   (*b*) annual,
   (*c*) diurnal;
2. Irregular (magnetic storms).

Secular Variations.—The magnetic poles do not seem to stay fixed, but oscillate like a pendulum. The north magnetic pole is now on its western sweep. An irregular curved line which connects the points on the earth where the needle coincides with the geographical meridian is called the *agonic line* (without an angle). Such a line in 1890 cut the eastern part of South America and passed up through the States of South Carolina, near Charleston, Ohio, and Michigan. Thus in New England the needle points west of north, but in most of the United States it points east of north. After a time this line will swing back to the east. The cycle is about 900 years. Observations of this kind have been recorded in Paris since 1580.

Isogonic lines are those connecting places on the earth's surface in which the declination is the same. A declination map portraying such lines has to be continually changed and determined by a magnetic survey.

Annual variations are slight, and greatest in spring and least in summer. They never exceed 15′ or 18′.

Due to *diurnal variations*, the north pole of the needle takes a westerly direction of 8′ to 15′ during the warmest part of the day; it then returns to its original position, and remains stationary during the night.

(2) *Irregular* or *accidental* variations are due to earthquakes, volcanic eruptions, and the aurora borealis. From the latter cause the needle may vary 7° or 8° in the polar regions. The sun seems able to produce widespread simultaneous disturbances in both magnetism and electricity. Such perturbations are called *magnetic storms*, and their maximum coincides with the maximum of "sun-spots."

Describe the mariner's compass.

This instrument depends upon the magnetic action of the earth on a declination needle, and is used in guiding the course of a ship. The needle is supported on a pivot in a hollow cylindrical brass case. The case is supported on *gimbals*, which are two concentric rings moving on axes at right angles to each other, so that the needle is always horizontal. The needle may also be floated on gasolene. On the needle is fixed a disk of mica which bears a tracing of a star or *rose* with 32 branches, making the eight points or *rhumbs* of the wind, the demi-rhumbs, and quarters. The branch called North and marked by a star corresponds to the needle beneath. The pilot, knowing the direction in which to steer, turns the rudder till the course coincides with the sight-vane on the inside of the box, which is parallel with the keel of the vessel. The inventor of the compass is not known. Its use is mentioned in the twelfth century, but probably the Chinese had used it long before.

What is inclination or dip?

The inclination is the angle which a needle makes with the horizon when it can move in a vertical plane around a horizontal axis. It is the movement *in* toward the earth. The needle must be placed

in the magnetic meridian, for when put east or west a dipping needle will be vertical.

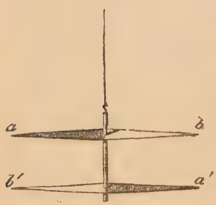
The magnetic poles are those places on the earth where the dipping needle is vertical. In 1830, Sir James Ross found the north one at 70° N. lat. and 96° W. long. The needle only lacked $\frac{1}{60}$° of pointing directly down. The same observer found a spot in the South Sea where the needle lacked 1° 20′ of pointing to the earth's centre. These do not at all correspond with the geographical poles. The magnetic equator, or *aclinic* line, is the one joining those places on the earth where there is no dip. *Isoclinic* lines connect places where the dipping needle makes equal angles.

What is the astatic needle and system?

An *astatic needle* (unsteady) is one uninfluenced by the earth's magnetism. By repeated trials a needle may be made astatic by placing a large magnet near it, which will neutralize the earth's magnetism.

An *astatic system* is a combination of two needles of the same force, joined parallel to each other, with poles in contrary direction. (Fig. 106). The opposite action of the earth's magnetism on a' and b, on a and b', just counterbalance each other, and the system sets at right angles to the magnetic meridian. This is useful as a test for electrical currents, the deflection of the system then being wholly due to electricity.

FIG. 106.



How is magnetic intensity determined?

The intensity increases with the latitude, and can be relatively determined by the number of oscillations a needle makes in regaining its equilibrium after disturbance. Count the number of oscillations during the same length of time at two places. The intensity at those places is proportional to the squares of the number of oscillations. The greater the number, the greater the intensity. The same is true for the pendulum. Lines connecting places of equal intensity are *isodynamic* lines. The intensity seems to vary with the time of day, being greatest between 4 and 5 P. M. There may also be a slight annual increase.

What are the laws of Coulomb?

Magnetic attractions and repulsions are directly proportional to the magnetic masses, and inversely as the squares of distances. Similar, therefore, to the laws of gravitation. This is proven in two ways: (1) torsion balance, (2) by oscillation. In the balance a wire is twisted through a certain space by a magnet, and the angle of torsion is proportional to the force of torsion.

What are magnetic curves and the magnetic field?

Scatter iron filings on a paper held near a horseshoe magnet. They will arrange themselves in thread-like curves, called *magnetic curves*, and each particle becomes a little magnet.

The *magnetic field* is the space in the immediate neighborhood of a magnet. This space undergoes some change in consequence of the presence of the magnet, and so different fields may be of different intensities. It is not good for a watch to bring it very near a dynamo.

What are the sources of magnetism?

1. Terrestrial magnetism;
2. Electricity.

In what ways may magnets be made?

1. From other magnets;
2. By earth's induction;
3. By electricity.

What are the methods of making magnets from other magnets?

1. Single touch;
2. Separate touch;
3. Double touch;
4. By contact;
5. By induction.

The *single touch* consists in moving the pole of a magnet from one end to the other of the bar to be magnetized, repeating the operation in the same direction.

The *separate touch* consists in placing the two opposite poles of two magnets of equal force in the centre of the bar to be magnetized, and in moving each toward the opposite ends of the bar; then repeat. Compass needles are best magnetized in this way.

By *double touch* two magnets are placed with opposite poles close together in the middle of the bar. The two poles are kept apart by a piece of wood placed between them, and they are moved first toward one end, and then from this to the other, and so on, finishing at the middle. This method gives powerful magnets, but may produce consequent poles.

How does the earth make magnets?

When a bar of soft iron is held in the magnetic meridian parallel to the dip, it becomes endowed with feeble polarity, the end toward the earth in the northern hemisphere being the north pole. This is unstable, and the poles may be reversed by reversing the bar. A certain amount of coercive force may be given it by hitting it with a hammer or by twisting it. Such feeble magnetism is often seen in lightning-rods, lamp-posts, rifles, etc. This serves the purpose of advertisers of so-called *magnetic spring-waters.* It is the vertical iron pipe containing the water which becomes magnetic; the water itself has no such property.

How is the magnetism of iron ships corrected?

This magnetism is present from three causes: (1) The earth exercises a *vertical induction* upon vertical masses of soft iron used in the ship; also (2) a horizontal induction upon deck-beams, etc.; and (3) the iron of the ship from the hammering and mechanical operations used in its construction may become permanently magnetized. All these factors greatly disturb the compass-needle, or even make it a useless or dangerous instrument. The first two effects may be corrected by "swinging the ship"—*i. e.* comparing the indications of the ship's compass with those of a standard compass placed on shore. By arranging vertical and horizontal pieces of soft iron near the steering compass, this is finally compensated, so that it points in all positions of the ship in the same direction as the one on shore. The third factor may be compensated by two permanent magnets placed near the compass in certain empirical positions. After a voyage the permanent magnetism of a ship is found to be partly destroyed by the buffetings of the waves, etc., and the compasses are then over-compensated. Many a vessel has been lost from this cause. After a time the ship's magnetic condition becomes permanent and unaltered by further wear and tear.

"Swinging the ship" is not as much done as formerly. A table of errors is made out, and the true course determined from it; or both methods may be used: compensate as much as possible, and then construct a table of residual errors.

Electro-magnets will be spoken of under Electricity.

What is a magnetic battery?

A magnetic battery or compound magnet consists of a number of magnets, either horseshoe or bar, joined together by their similar poles. They give an increase of power, but mutually enfeeble each other, so that a combination of six is not six times as strong as one alone.

Armatures or *keepers* are pieces of soft iron placed in contact with the poles. They act inductively and are acted on inductively, preserving, or even increasing, the permanent magnetism of the bars.

The *portative force* of a magnet is the greatest weight which a magnet can support. The horseshoe magnet is the best form for supporting weights, for then both poles can act.

What circumstances influence the power of magnets?

1. Temper; hardest is best.
2. Proportion of C; least is best—must be some.
3. Increase of T. weakens a magnet. A magnet heated red hot is indifferent to iron and other magnets. This is the *magnetic limit.*
4. Percussion, as hammering, increases magnetism; falling is bad.
5. Torsion diminishes magnetism.
6. Hollow tubes make better magnets than solid bars.

Floating magnets arrange themselves in geometrical forms when a strong magnet is held over them, showing reciprocal action of their poles.

Perpetual motion with a magnet is just as impossible as with gravitation.

Magnets are not sources of energy. The force of attraction will do a certain amount of work, but to restore the attracted body to its former position requires just as much work as was originally performed by the magnet.

What are the uses of magnets?

1. For making compasses;
2. For making other magnets;
3. For detecting and measuring electric currents, astatic needle in galvanometer;
4. Inducing electric currents;
5. Electro-magnet in telegraph and telephone.

CHAPTER XXIV.

STATICAL ELECTRICITY.—ATMOSPHERIC ELECTRICITY.

What is electricity and its history?

Nobody knows what it is. Its nature is that of a powerful physical agent which manifests itself by attractions and repulsions, by luminous, heating, and chemical effects, and by violent commotions, as in lightning.

It is not inherent in bodies like gravity, but has to be developed in them by friction, chemical action, magnetism, etc.

Thales in 600 B. C. rubbed amber with silk and found it could attract light bodies. Amber in Greek is *electron*, hence the derivation of the word *electricity*.

In the sixteenth century, Dr. Gilbert, physician to Queen Elizabeth, took up experiments with amber, sulphur, wax, glass, etc. Otto von Guericke invented the first electrical machine and the first air-pump in about 1650. In 1780, Galvani experimented with frogs' legs: this was the real beginning of practical electricity.

What are the kinds of electricity?

1. Magnetism;
2. Statical, frictional, Franklinic, or electricity at rest. Two fluids are assumed, which are separated by mechanical friction;
3. Galvanic, dynamic, current, or electricity in motion. The two fluids are separated by molecular friction.

Frictional or Statical Electricity.

How is this variety manifested?

1. By attraction first, and then repulsion;
2. A cobweb feeling on the skin;
3. A spark from knuckles when presented to an electrified body.

What are conductors and non-conductors?

According to the greater or less resistance which a body offers to the passage of electricity, we have conductors, semi-conductors, and non-conductors or insulators.

Electrical conductivity is the reverse of electrical resistance. No sharp line can be drawn between the following substances; the transition is gradual. This list is in order of decreasing conductivity:

Conductors.	Semi-conductors.	Non-conductors.
Metals,	Alcohol,	Dry oxides,
Charcoal,	Ether,	Ice at —25° C.
Graphite,	Dry wood,	Rubber,
Water,	Paper,	Dry air and gases,
Animals,	Ice at 0° C.	Silk,
Linen,		Diamond,
Cotton.		Glass,
		Wax,
		Sulphur,
		Resins,
		Amber,
		Shellac.

Water is a good conductor for statical electricity, but not for dynamical, which is of low pressure. Experiments are best conducted in a clear, cold, dry atmosphere.

A conductor remains electrified as long as it is surrounded by a poor conductor or insulator. Otherwise, the electrified body would discharge its supply into the earth, which is a good conductor. Therefore the earth has been called the *common reservoir*.

What are the kinds of frictional electricity and the theories?

The electricity on glass is the *positive* or vitreous, and that on the

silk rubber is the *negative* or resinous. This latter is also produced on sealing-wax, and then the catskin holds the positive variety.

The theories are two—Franklin's and Symmer's. (1) Franklin assumed one subtle imponderable fluid which pervades all matter. By friction certain bodies can acquire an additional supply of it, and are positively electrified; others lose a portion, and are negatively electrified—a positive excess and a negative deficiency. This view is now abandoned.

(2) Symmer assumes two subtle imponderable fluids in every substance—a positive and a negative. When they are combined they neutralize each other, but by friction or other means they may be separated, and, as there is a greater or less excess of one or other in a body, it is electrified positively or negatively.

What is the law of action of electrified bodies?

Bodies charged with the same electricity repel each other, and with opposite electricities attract each other. A law similar to that for magnetism.

How is frictional electricity developed and determined?

Rub a glass rod with silk, or a piece of sealing wax with catskin, and the parts rubbed will be found to have the property of attraction and repulsion. The neutral electricity is decomposed. Two electricities are developed at the same time and in equal quantities; one body takes the positive and the other the negative electricity. Glass takes + when rubbed with silk, but — when rubbed with catskin. In the following table any body becomes positively electrified when rubbed with any of those following it; negatively, if rubbed with any of those preceding:

1. Catskin.	7. Silk.	12. Sealing-wax.
2. Flannel.	8. The hand.	13. Resin.
3. Ivory.	9. Wood.	14. Sulphur.
4. Rock crystal.	10. Metals.	15. Gutta-percha.
5. Glass.	11. Caoutchouc.	16. Gun-cotton.
6. Cotton.		

In order to determine whether bodies are electrified or not, *electroscopes* are used. The simplest is the electric pendulum, consisting of a pith ball attached by a silk thread to a glass support. A solid

body may also be electrified by friction with a liquid or with a gas; under certain conditions all bodies may be electrified by friction.

In what other ways may frictional electricity be developed?

1. Friction;
2. Cleavage;
3. Pressure;
4. Heat.

Cleavage is a source of electricity, seen in case of mica and lumps of sugar. Opposite electricities are produced in the parts broken if they are poor conductors.

Pressure, followed by sudden separation, causes electrical excitement. A disk of wood pressed upon an orange will carry away quite a charge of electricity.

Heat causes electricity, best seen in tourmaline. Pyro-electricity is the name given to such phenomena, and they are intimately connected with the crystalline form of the mineral. They are only seen in hemihedral crystals (one end not symmetrical with the other). Different electricities will be at the opposite ends of the crystal. Topaz, silicate of zinc, cane-sugar, tartrate of K belong to this class.

What are the laws of electrical attraction and repulsion?

These laws are identical with those of gravitation—viz. (1) *The repulsions or attractions between two electrified bodies are inversely as the squares of their distance; and* (2) *directly as the product of the quantities of electricity with which they are charged.*

These laws were determined by means of the torsion balance, which was also used for the laws of magnetism.

How is electricity distributed?

This depends on the extent of surface, and not on the mass. Electricity does not penetrate the interior, but is confined to the surface, unless in case of a discharge through a wire. This fact can be illustrated by electrifying a hollow copper sphere, a long strip of tinfoil, or a bird-cage. Sparks may be taken from the outside of the cage, but the bird and contents of cage will be wholly unaffected. In case of ovals or ellipsoids electricity tends to collect on extremities and at the most acute points.

This property of electricity is due to repulsion; it tends constantly to pass to the surface of bodies, and thence to escape, but is prevented by the resistance of the feebly-conducting atmosphere.

Electrical density or *thickness* is the term used for the quantity found on a given surface.

The loss of electricity is due to what?

1. Imperfection of insulating supports;
2. Conductivity of air.

In an ordinary vacuum all electricity escapes, the pressure of the insulating atmosphere being removed. The earth is always taken at zero potential; anything higher is positive potential; anything lower, as free —E, is negative potential.

How may electricity be transferred?

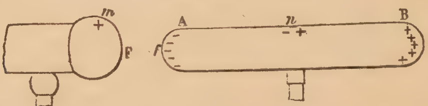
(1) By conduction;
(2) By convection;
(3) By discharge:
 (*a*) slow dissipation;
 (*b*) disruptive, as by spark, brush, glow, or dark discharge.

(1) If the conducting power be overtaxed, heat is produced, and metals may be thus melted or vaporized. (2) Convection is another way, but not here due to gravity, as in case of heat. Molecules are repelled and go away, and others come in, and to this is due the usual loss in experiments. (3) The discharge varies with the nature and shape of the conductors and the difference of potentials.

Describe electrical induction.

In Fig. 107 the + electricity of F separates the neutral electricity

FIG. 107.



of A B, and holds the — next to itself on A, and repels the + to B. At N is a neutral point. By touching B with the finger, and

then removing this conductor from the influence of F, A B can be charged with — electricity alone.

Describe the gold-leaf electroscope.

An *electrometer* measures electricity. A galvanometer and torsion balance detect and measure electricity. The pith-ball electroscope is not very delicate, and the gold-leaf variety shows the presence of electricity, and also its kind. A glass jar has a metal rod passing through its cover and terminating above in a knob and below, inside the jar, in two strips of gold-leaf. The air in the interior is dried by quicklime. When an electrified body is brought near the knob, it decomposes the neutral electricity of the system, attracting to the knob electricity of the opposite kind, and repelling electricity of the same kind to both leaves, which consequently diverge.

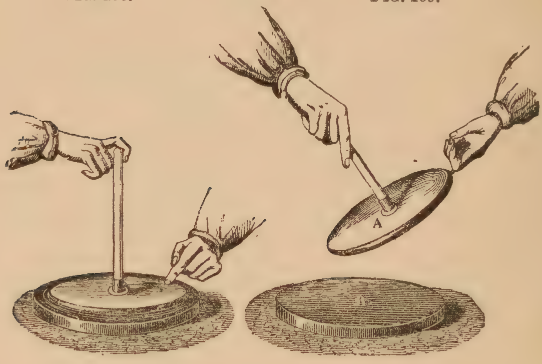
To ascertain the *kind* of electricity, suppose the system charged with + E. This can be done by bringing — E. near the knob. This holds + E. next to it by induction, and if a finger touches the lower part of the knob, it will take off — E. Now remove the finger, then the electrified body, and + E. will spread over the system and cause the leaves to diverge. If an excited glass rod be now approached, it will repel + E. to the leaves, and cause them to diverge more widely. If an excited shellac rod be presented, the leaves will collapse, being attracted by the opposite electricity.

What are some of the electrical machines?

The electrophorus, or electricity-bearer, was invented by Volta. Its principle, like that of all other electrical machines, is that of induction. In Fig. 109 B is a cake of resin placed on a metallic surface or in a *form* lined with tin-foil. The *cover* is a metal disk with a glass handle. Flap the resin with catskin and it becomes charged with — E. Then put on the cover, and owing to the minute roughnesses of the resin, it only comes in contact with a few points, so that the resin does not lose its charge, being a poor conductor. It induces + E. on the under surface of the cover, and — E. is repelled to the upper surface. Now take off this free and repelled — E. by touching the upper surface of the cover with a finger (Fig. 108). Remove the finger, immediately raise the cover from the resin, and it will be charged throughout with + E. If a knuckle is brought near it a smart spark passes.

The metallic form on which the cake rests is important, as it increases the quantity of electricity and makes it more permanent.

FIG. 108. FIG. 109.



What are the chief types of plate machines?

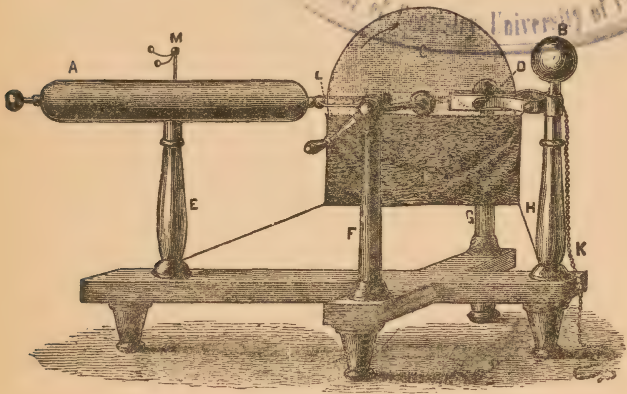
1. Simple plate;
2. Holtz continuous electrophorus;
3. Wimshurst's.

The first used was a ball of sulphur rotated between the hands (Von Guericke). Next was a ball of resin, and next a globe of glass; in each case the hand acted as a rubber. Next came a cylinder of glass rubbed by cushions, and finally a plate of glass.

The simple plate machine consists of a positive or prime conductor A (Fig. 110) and a negative conductor B. C is the glass plate, and D the rubber made of leather and amalgam. E, F, G, H, are insulated supports, and I a silk insulating bag. K is a chain used to connect either conductor with the earth. On one end of the prime conductor at L are two combs, one on either side of the plate. M is a pith-ball electroscope. When the plate is turned friction generates + E. on the glass and — E. on the rubber. As the electrified plate comes opposite the combs it attracts — E. and repels + E. The reason that this end of the conductor is a series of points is that the attracted — E. may readily escape to the plate, and there it will neutralize the + E. of the glass, leaving the conductor charged

with + E. alone. One of the conductors must be connected with the earth, or the mutual attraction of the two kinds of electricity

FIG. 110.



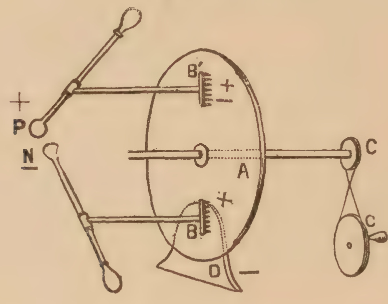
will prevent a heavy charge in either. If + E. is wanted connect B with the earth; if — E, connect A.

Describe the Holtz machine.

It consists of two glass plates, one a little larger than the other, placed 3 mm. apart. The posterior one is insulated and stationary, and has two windows cut in it at the opposite ends of any diameter. The anterior or smaller plate can be rotated, and has in front of it two brass combs which are connected respectively with two brass rods terminating in knobs. There are pasted upon the edges of the windows in the stationary glass tongues of thin cardboard coated with shellac. These are called the armatures, and serve the purpose of an electrophorus. To work the machine, one of these armatures has first to be *primed*—*i. e.* electrified—for example, with a piece of hard rubber. The whole working is complex, but the principle is illustrated in Fig. 111. A is a revolving glass plate situated between D, a piece of hard rubber, and a comb B. D corresponds to the armatures mentioned above. Let — E. be excited on D with catskin. It will induce + E. across the glass on comb B, and repel — E. to N. But the comb readily gives up its + E. to the revolv-

ing glass; so the system B N is left charged with free — E. When the glass disk has made a half revolution, that part charged with + E. arrives at comb B′, and polarizes B′ P, repelling + E. to P, and drawing off the induced — E. from B′. Thus the two conductors will always be charged with the opposite electricities, and a steady flow of sparks passes between P and N. The power of the

FIG. 111.



machine is strengthened by suspending from the conductors two *condensers*, which are only two small Leyden jars. Becoming charged by the working of the machine, and discharged at the same rate by the knobs, they strengthen the spark, which may be 6 or 7 in. long.

Describe Wimshurst's machine.

This is the simplest and most efficient of all induction machines. It consists of two circular glass disks, about $\frac{1}{4}$ in. apart, mounted on a fixed horizontal spindle in such a way as to be rotated in opposite directions. Both disks are well varnished, and attached to the outer surface of each are narrow radial sections of tin-foil. Attached to the spindle on which the disks rotate is a bent conducting rod, at the ends of which are two fine wire brushes. At the back is a similar one at right angles to that in front. There are two forks provided, with combs directed toward each other and toward the two disks which rotate between them. The combs are supported on Leyden jars, to which are also attached the dischargers.

The machine is entirely self-exciting, and requires neither friction nor outside starter to excite it. The initial charge is probably obtained from the electricity of the air. A machine with 12 plates 30

in. in diameter produces sparks 13½ in. long. Its method of action is not fully understood.

What are some of the experiments with electrical machines?

The spark, according to its length, may be a straight line, a curve with branches, or a zigzag. One may be obtained from an electrified human body standing upon an insulated stool.

The *electrical chimes* consists of three electrified bells which attract and then repel little brass balls placed between them. The *electrical whirl or vane* is made of radiating pointed wires, all bent in the same direction, fixed to a central cap placed on a pivot. When placed on a prime conductor, it will revolve in a direction opposite to that of the points, due to the escape of electricity from a point and a repulsive action of the electrified air. It would not whirl in a vacuum. It is stationary in water, which is a good conductor, but rotates in olive oil, which is a poor conductor. The blast of electrified air can be felt or it may blow out a candle.

Condensation of Electricity.

Describe a simple condenser.

A condenser stores up a large amount of electricity on a small surface. It consists in all cases of two insulated conductors, separated by a non-conductor; the principle is induction.

Any of these condensers may be discharged by connecting the two plates. It may be done slowly or instantaneously: if by the latter way, a *discharging-rod* is used, consisting of two bent brass rods united by a hinge and provided with glass handles. A discharge does not consist in a simple union of positive and negative electricities, but a series of partial discharges or oscillating currents, alternating in opposite directions.

What is Franklin's plate?

Franklin's plate, or the *fulminating pane*, consists of a sheet of glass held in a wooden frame and partially covered on both sides by strips of tin-foil; one strip is insulated, and the other connected with the earth. After being charged connection is made by touching both coatings; if by the hands, a violent shock is felt, the combination taking place through the body.

Describe the Leyden jar.

The Leyden jar (named from a town) was accidentally and painfully discovered by a Frenchman in 1745 while charging a jar of water. It is a modified condenser or fulminating pane rolled up. It consists of a glass bottle of any convenient size coated inside and out for about two-thirds of its height with tin-foil, or the jar may be filled with gold-leaf, using no tin-foil inside. Through a perforated cork passes a rod, terminating in a knob and communicating with the inner tin-foil. Like any condenser, it may be charged by connecting one coating with the ground and the other with the source of electricity (Fig. 112). The ground connection may be made by

Fig. 112.

hand, and + E. on the inner coating will hold − E. on the inner surface of the outer coating, next the glass. The repelled + E. goes off through the hand, and is not felt. It may also be charged by holding it by the knob and presenting the outer tin-foil to the machine. It is best discharged by the discharging-rod.

Where does the electricity reside in a Leyden jar?

It resides *in* or *on* the surface of the glass. The tin-foil is only a conductor, collecting electricity, while the glass holds it. This can be proven by a charged jar with movable coatings. It may all be taken apart and placed on a table. If put together again, it can give a shock nearly as great as before. The glass, being a poor conductor, did not lose its charge.

The amount of charge depends upon the extent of surface, and is inversely as the thickness of the glass. There is also a *residual* charge, as though electricity had entered the glass. A second spark can be taken after the jar is allowed to rest a short time.

What is a Leyden battery?

Leyden batteries are made of a series of such jars, whose outside and inside coatings are respectively connected with each other. Serious or fatal results may occur from such batteries. Touch the discharging-rod to the outside coating first.

What are the effects of electric discharge?

(1) Physiological;
(2) Luminous;
(3) Heating;
(4) Magnetic;
(5) Mechanical;
(6) Chemical.

(1) The physiological effects are those produced on living beings or on those recently deprived of life; they are shown by the sensibility and contractility of organic tissues or by violent muscular contractions. A charge of a Leyden jar was passed through a regiment of 1500 men as they joined hands.

(2) The color of the spark varies with the nature of the bodies, the surrounding medium, and the pressure. In air it is white and brilliant, and its spectrum full of dark lines; in vacuo it is violet; in H it is reddish; and between charcoal points it is yellow. There may be an actual transference of matter, accounting for these different colors. Geissler's tubes, the electric egg, the luminous square and bottle are constructed to show luminous effects. If bits of tin-foil be pasted on a glass at slight intervals, so as to represent any object, we may get a reproduction of such object in luminous flashes as sparks leap across from one tin-foil to another.

(3) The spark is also the source of most intense heat. Substances are thus vaporized to get their spectra. Illuminating gas may be thus ignited or mines and blasts exploded.

(4) Discharging a spark at right angles to a steel wire or needle makes a permanent magnet of it, or the needle may be magnetized by putting it in the centre of a coil of fine copper wire and passing a spark through the wire.

(5) The mechanical effects are violent lacerations, fractures, and sudden expansions, which ensue when a powerful discharge is passed through poor conductors.

(6) The chemical effects are decompositions and recombinations. Two gases may be combined or compound ones be decomposed. Water, NH_3, C_2H_4, and H_2S may be decomposed. The chemical effects of statical electricity are by no means so varied as those of dynamical.

What is the duration of the spark and velocity of electricity?

The duration of the spark has been determined by reflection from rotating mirrors. Wheatstone found it to be $\frac{1}{24000}$ sec., but Lucas and Cazin consider it to be between 23 and 46 ten-millionths of a second.

The velocity was also determined by catching reflected sparks on a revolving mirror. When the sparks pass between knobs $\frac{1}{10}$ in. apart, but with $\frac{1}{4}$ mile of wire interposed, the velocity is found to be 288,000 miles per sec.—50% greater than that of light. By some the velocities of light and electricity have been thought to be the same; and this is very plausible.

The velocity of dynamical electricity in wires is far less than the above, and through submarine wires is comparatively slow. It is about 62,000 miles per sec. in iron telegraph wires or 111,000 in copper ones. Delayed telegrams are therefore not due to slow electricity.

Atmospheric Electricity.

What did Franklin prove?

The atmosphere always contains some free electricity; it is usually +, and that of earth is —. It may be caused by friction of layers of atmosphere.

Lightning is the light of the electric spark which shoots from cloud to cloud or cloud to earth when oppositely electrified. A Leyden jar can be charged in a rain-storm by means of a kite. A Russian physicist was killed in experimenting with electricity from a lightning-rod.

Franklin in 1752 discovered the identity of lightning and electricity by means of his kite experiment. There are six points of resemblance:

1. Mechanical effects—fractures non-conductors;
2. Fires combustibles;

3. Heats substances and melts them;
4. Gives shocks;
5. Has odor of ozone—brimstone smell;
6. Flash of lightning resembles the ordinary zigzag spark. Its duration is less than $\frac{1}{1000000}$ sec. It can be photographed.

Thunder is the sound resulting from the concussion of air at the passage of the spark or from the condensation of air: it can be heard about fifteen miles.

What is the use and proper arrangement of lightning-rods?

As the principle of lightning is induction, it may be possible for the electricity of a high object on earth to escape slowly by points, and so prevent an instantaneous discharge, as between a cloud and a house. This is the object of lightning-rods, but should the potentials of the opposite electricities be too great, the rods must be of sufficient size and so applied as to conduct the sudden discharge to the earth and not to the house.

Good rods, properly applied, absolutely protect a house; bad ones invite disaster. The whole subject was recently investigated by a convention in England, and the following points were established:

(1) The space protected by a rod is a cone the height of which is the height of the rod, and the diameter of its base is one and a half to two times the height of the rod.

(2) The upper end of the rod should be solid and sharp, and should have radiating from its sides near the extremity four sharp points; stretch barbed wire along all sky-lines and run to the ground at each corner of the house.

(3) The material for the rod should be Fe or Cu. Iron is the best for use. May use an Fe pipe 1 in. in diameter packed with C.

(4) *Size.*—If Fe is used, it must have six times the sectional area of Cu. The minimum cross-section for Cu is .1 in.; better be .4 in. The minimum for Fe is $\frac{2}{3}$ in.; better be 1 in.

(5) Get a large surface, square, or a wire bundle.

(6) Joints must be perfect. A tape of Cu can be used, having no joints.

(7) Paint the rods except at the points.

(8) Glass insulators are of no use; may use metallic clamps. A system of gas- or water-pipes or a metallic roof should not be connected with the rod.

(9) The ground connection is most important. Carry end of rod below the level of ground-water into an old well or water-course, and surround its base with old iron or charcoal, all being good conductors.

CHAPTER XXV.

DYNAMICAL ELECTRICITY.—BATTERIES.—ELECTRICAL UNITS.

What is the history of dynamical electricity?

The frog was the founder of it, and had already been used as an electroscope for electrical machines. Galvani, a professor of anatomy at Bologna, experimented with a frog in 1780, and thought the legs and nerves represented a Leyden jar. On connecting the lumbar nerves of a dead frog with the crural muscles by a metallic circuit, the muscles were briskly contracted as though the nerve were +, the muscle —, and the rod a discharger. He said that a "vital fluid" flowed along this rod, and he paid most attention to the animal. He found, however, that he got best results when his metal conductor was made of Zn and Cu.

Alexander Volta, a professor of physics at Pavia, made up his mind that the contraction was due to contact of dissimilar metals, and the frog acted as a discharger.

Fabroni, a countryman of Volta, thought the phenomena due to chemical action, noticing that the zinc was oxidized.

Great controversies arose, but it seems that the *contact* and *chemical* theories are both true: more recently opinion has inclined toward the contact theory. In England, Wollaston, Davy and Faraday supported the chemical theory.

Discuss current electricity.

When a plate of Zn and one of Cu are partially immersed in dilute H_2SO_4, no chemical or electrical change is apparent beyond

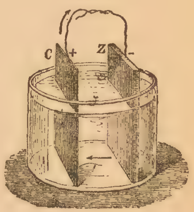
the disengagement of a few H bubbles on the Zn plate. If the two be placed in direct contact, or better, be connected by a wire, chemical action sets in and H bubbles in large quantities collect, not on the Zn, but on the Cu plate. If the wire be examined, it will be found to possess remarkable heating, magnetic, and other properties. When two spheres are charged with statical electricity, one + and the other —, a connecting wire equalizes their potentials. If we can imagine some agency which renews the different electrical conditions as fast as they are discharged, the phenomena in the wire will be continuous. This is what takes place when two metals are in contact in a liquid which acts upon them unequally; the rapid equalization of potentials in the wire is continuous, and is called the *electrical current.* It may be illustrated by the condition which determines the flow of water between two reservoirs at different levels. If the lower reservoir be so large that water added would not affect its level, as the sea, and if the higher one could be kept at a constant level, there would be a constant flow between them. In speaking of *current* in electricity, nothing actually flows; there is no transference of matter. We speak of current much in the same sense as we say sound and light travel. Electricity does not travel through tubes like water, but through solids, and does not seem to overcome any inertia.

Describe a voltaic cell.

A voltaic *element*, *couple*, or *cell* consists of two metals in metallic contact placed in a conducting liquid.

A *battery* is a series of cells properly connected. The chemical action upon one metal must be greater than upon the other, and the metal most attacked is called the positive or generating, and the other one is the negative or collecting plate.

FIG. 113.



The direction of the current *in* the liquid is always from the plate most attacked.

The pole or electrode (way of electricity) of a plate is the terminal of the plate or end of a conductor attached to the plate (Fig. 113). Now, the —plate (*e. g.* Cu) has the + pole and Zn the — pole; so we must not confound poles with

plates. In speaking of direction, that of the + electricity is always understood. Dr. E. Curtis uses the following mnemonic:

copPer ziNc.

The big P means that Cu has the Positive Pole and Pours electricity. The big N means that zinc has the Negative pole and "Nabs" electricity.

What is an electro-motive series?

An electro-motive series consists of a list of the most electro-positive and electro-negative substances: the former are at the first of the list. When any two of these are connected, the current in the wire proceeds from the one lower in the list to a higher one. The mere immersion of two different metals in a liquid is not sufficient to produce a current; there must be chemical action. Zn is most often the + element, but not always; it depends upon the fluid. A solution of Na_2S would change the direction of current with Zn and Cu, and the latter would be the + plate.

Zinc,	Iron,	Silver,
Cadmium,	Nickel,	Gold,
Tin,	Bismuth,	Platinum,
Lead,	Antimony,	Graphite.
	Copper,	

Define potential and electro-motive force.

Potential, electro-motive force, pressure, and tension are similar terms.

Potential is the difference in electrical conditions. It represents a stored force, and is present before the wires are connected. The current tends to diminish it, but chemical action restores it. It is to electricity what temperature is to heat. Lightning has high potential and but little electricity; a voltaic cell has small potential and much electricity. Potential and quantity are comparable to a barrel of water placed on a height and a pond of water at a lower level. The force in each drop of water in Niagara depends on the height of the falls, and not on its association with other drops.

Electro-motive force is the force by which the current is impelled forward, by which it is set in motion. It bears the same relation to electricity that pressure does to water, and is proportional to the

number of cells. It depends upon the material, and not upon the size of the plate, and is greater in proportion to the distance of the two metals from each other in the above series.

Cells and Batteries.

Cells are of two kinds—the *one-fluid* cell and the *two-fluid* cell. The elements of a battery are the cells which compose it. The elements of a cell are the metals, the fluid, etc., which compose it.

Describe the voltaic pile.

The voltaic pile or battery was devised by Volta himself. It consists of a series of disks of Cu, cloth, and Zn piled one upon the other. At the bottom, on a framework of wood, is a Cu disk, then one of cloth moistened with acidulated water or brine, then one of Zn, and so on. They are kept in vertical position by glass rods. The highest disk is Zn, and is the — pole; the lowest is Cu, and is the + pole; the current flows in the wire connecting them.

What was the "crown of cups," Cruikshank's, and Wollaston's batteries?

The *couronne de tasses* is said to have been invented by Volta in 1800, before the voltaic pile was devised; others say that Davy invented it. The elements were placed in a circle, each containing a Zn and a Cu plate immersed in a solution of salt in water. The Cu of each cup was joined to the Zn of the next.

Cruikshank improved upon this by soldering Zn and Cu plates together and cementing them water-tight into a trough, which thus becomes divided into a series of cells for the reception of the exciting liquid. These batteries were of enormous size. Wollaston used a similar method. Each Zn plate was surrounded with a sheet of Cu, not touching, and this constituted a couple which could be immersed in the vessel containing the dilute acid, usually $\frac{1}{16}$ H_2SO_4 and $\frac{1}{20}$ HNO_3. A number of couples were fixed to a cross-frame. The Cu of one was soldered to the Zn of the second, and this in turn was surrounded by the second Cu, and so on. The effect was equal to that of a dynamo, but lasted only for a few minutes.

Describe Hare's deflagrator.

Hare rolled together large sheets of Cu and of Zn in form of a

spiral, but preserved from direct contact by bands of leather or horse-hair. The whole was immersed in a vessel of acidulated water, and the two plates were connected outside the liquid by a wire. It is called *deflagrator*, on account of its great heating effects.

To what is the enfeeblement of currents due?

In the simple cell and in the batteries above mentioned there is the objection that the currents rapidly diminish in strength. This is due to three causes:

(1) Neutralization of the acid;
(2) Local action;
(3) Polarization.

(1) The first is necessary, for the current depends upon the using up of the acid and Zn. The remedy is replacement of more acid and Zn.

(2) All commercial Zn contains impurities, as C and Fe. If such a plate is immersed in dilute H_2SO_4, each particle of Fe forms a separate little voltaic cell with the Zn. This "coasting trade" between the Zn and the impurities upon its surface diverts so much from the regular battery-current, and weakens it. It also wastes chemicals, because these local or secondary currents continue when the regular current is broken. The remedy is to rub Hg over the Zn, called *amalgamation*. That covers up impurities, and the amalgamated Zn then behaves like pure Zn.

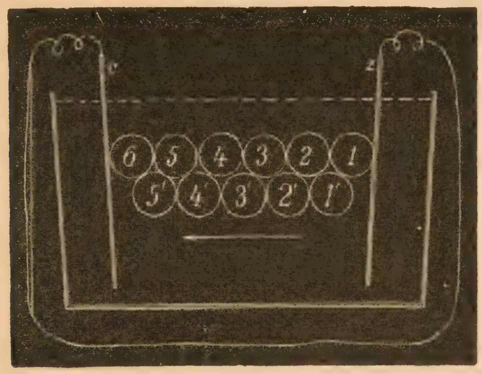
(3) Polarization means the collecting of bubbles of H on the negative plate—*e. g.* on the Cu plate. The liberated H has nothing to unite with chemically, and a plate coated with H is more electro-positive than usual, and the difference of potentials between the two plates becomes less and less, and there is a tendency to produce a current in the contrary direction to the principal one, and so destroy it wholly or partially. The Cu plate tends to become a plate of H. The H bubbles may be brushed off by a swab or the Cu plate be exposed to air.

Why does H appear at the Cu plate?

In Fig. 114 let the circles 1, 2, 3, etc. represent molecules of H_2SO_4, connecting the plates. The SO_4 of molecule 1 unites with a molecule

of Zn, and sets free H_2. This instantly unites with SO_4 of molecule 2, forming a new molecule, 1′, and so on till H_2 is set free at 6.

FIG. 114.



This theory of Grotthuss is insufficient, as it requires a finite force within the electrolyte which has never been observed.

Kohlrausch supposes electrolytic conduction to consist of actual motion of free and charged ions; a procession of + kathions moving toward the kathode, and one of — anions toward the anode. The cause of this motion is the difference of potentials at the electrodes.

Describe the Smee cell.

Polarization can be remedied by mechanical or chemical means. The Smee cell is an example of the former class. A silver plate or one of platinum is coated with a fine powdery deposit of Pt, which makes it so rough that H will not readily cling to it. This plate is suspended between two Zn plates, but not allowed to touch. Dilute H_2SO_4 is the liquid used, 1 to 7 in strength. Elements are Ag + Pt powder, Zn, dil. H_2SO_4.

Walker's cell is similar, where platinized graphite is used for the — plate. This battery is much used for telegraphy in England.

A battery may be made by causing the Cu plate to revolve in the liquid, preventing deposition of H by friction. Not a very practical method.

No mechanical means can wholly prevent polarization; it can only

be accomplished by placing the inactive metal in some liquid which will chemically combine with the H, thus using two fluids.

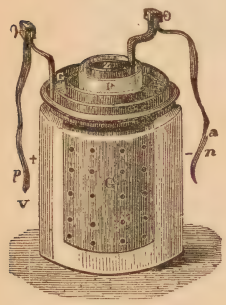
What are constant batteries?

With few exceptions the single-fluid batteries have been replaced by two-fluid batteries, which give a *constant* current for some time, as polarization is prevented. $CuSO_4$ is a good depolarizer, so is HNO_3 and chromic acid, H_2CrO_4. In most cases the two liquids are separated by a porous cup, which allows the H to pass through, but hinders to a large extent the mixture of the two liquids.

Describe Daniell's cell.

Daniell in 1836 invented the first constant battery. A glass vessel contains a sat. sol. of $CuSO_4$, and in it is immersed a Cu cylinder, G, open at both ends and perforated by holes (Fig. 115). Inside this cylinder, at its upper part, is a shelf for the support of crystals of $CuSO_4$. Also inside is a porous vessel P of unglazed earthen containing dil. H_2SO_4. In this cup is placed the + metal, Zn. A modern form has the Zn and H_2SO_4 on the outside. When the element is closed the chemical action is

FIG. 115.



$$Zn + H_2SO_4 = ZnSO_4 + H_2;$$
$$H_2 + CuSO_4 = H_2SO_4 + Cu.$$

The H_2 passes through the porous cup and is liberated on the Cu plate. It there meets the $CuSO_4$, which is reduced and forms sulphuric acid and metallic Cu. This latter is deposited on the Cu plate, and the H_2SO_4 permeates the porous partition and tends to replace that used up by the Zn. The solution of $CuSO_4$ would soon be exhausted if it were not kept saturated by the supply of $CuSO_4$ crystals on the shelf. To form a battery the Zn of one cell is connected with the Cu of the next, and so on. E.M.F. 1.072.

$$\text{The elements are} \begin{cases} Zn + H_2SO_4 \text{ dil.} \\ \quad\text{Porous cup.} \\ Cu + CuSO_4 \text{ sol. and crystals.} \end{cases}$$

Describe Grove's cell.

Here great E.M.F. is obtained by using a — plate of Pt instead of Cu, and by surrounding it with HNO_3 instead of $CuSO_4$. Note that the Zn plate is here on the outside. A glass vessel is partly filled with H_2SO_4 (1 to 8). Next comes a cylinder of Zn open at both ends, and inside this is a porous vessel containing ordinary HNO_3. Immersed in this is a plate of Pt bent in form of an S and fixed to a cover to keep back irritating orange-colored fumes of nitric oxide. The H_2 coming through the cup upon the Pt is disposed of thus:

$$2HNO_3 + 3H_2 = 4H_2O + N_2O_2.$$

The objection to this form of battery is the expense of the Pt and the suffocating gas N_2O_2. If NH_4NO_3 is mixed with the HNO_3, these fumes are almost wholly decomposed.

The Tyndall-Grove form is a modification, having a hard-rubber case, a shallow cup of HNO_3 containing a small strip of Pt, and the Zn is a flat thick plate with radiating arms. This form may be used for electric lights, but runs down soon and does not hold much acid. The E.M.F. of a Grove cell is 1.8 to 2 volts, 80% greater than a Daniell, and its internal resistance is 20% of a Daniell; so its strength is about nine times greater.

$$\text{Elements are} \begin{cases} Zn + H_2SO_4 \text{ dil.} \\ \text{Porous cup.} \\ Pt + HNO_3. \end{cases}$$

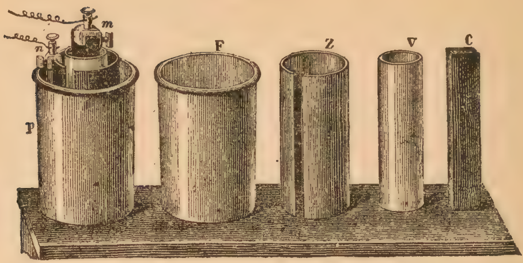
Describe the Bunsen cell.

This variety is known as the zinc-carbon cell. It is a Grove's, where the expensive Pt is replaced by a cylinder of C. In 1843, Bunsen suggested a peculiar kind of C, either that from gas retorts or a compressed mixture of coke and coal.

The vessel F (Fig. 116) contains H_2SO_4. Z is a hollow cylinder of amalgamated Zn. V a porous cup for HNO_3, which shall contain C, the rod of carbon. It is cheaper than Grove's, and the E.M.F. is about the same.

$$\text{The elements are} \begin{cases} Zn + H_2SO_4 \text{ dil.} \\ \text{Porous cup.} \\ \text{Gas carbon and } HNO_3. \end{cases}$$

FIG. 116.



Callan substituted cast iron for the C, and if the HNO_3 is very strong no fumes are given off.

How does chromic acid depolarize?

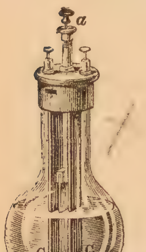
In these nitric-acid batteries the fumes may badly corrode the appointments of a laboratory, and chromic acid may be used instead of HNO_3; *i. e.* a mixture which produces chromic acid:

Take	water,	66%	by wt.
"	sulphuric acid,	25%	"
"	potas. bichromate,	9%	"

The chromic acid is reduced by the H_2 to chromic oxide, which unites with H_2SO_4 and forms chromic sulphate:

$$2H_2CrO_4 + 3H_2 = Cr_2O_3 + 5H_2O;$$
$$Cr_2O_3 + 3H_2SO_4 = Cr_2(SO_4)_3 + 3H_2O.$$

FIG. 117.



Describe the Grenet cell: what is electropion?

The above depolarizer is used in the Grenet cell or bottle battery (Fig. 117). Two carbon plates are stationary in the liquid, and between them can be plunged a Zn plate. This is withdrawn when the battery is not in use. There is no porous cup, and the cell may be said to be one-fluid, and this fluid is the mixture given above, and is called *electropion:* it is officinal. It can also be readily made of 1 part of the potash salt, 2 of H_2SO_4, and 10 of H_2O. This produces potassium sulphate and the depolarizer, chromic acid, thus:

$$\overbrace{K_2Cr_2O_7 + H_2SO_4 + H_2O}^{\text{Electropion.}} = K_2SO_4 + 2H_2CrO_4.$$

The reaction of H_2 with pure H_2CrO_4 is given above, but that is not quite correct for this mixture, where chrome alum is a product:

$$K_2Cr_2O_7 + 4H_2SO_4 + 3H_2 = \overbrace{K_2SO_4 + Cr_2(SO_4)_3 + 7H_2O}^{\text{Chrome alum.}}$$

Bichromate of sodium, $Na_2Cr_2O_7$, is better than bichromate of potassium, for it gives no chrome alum and makes more soluble compounds.

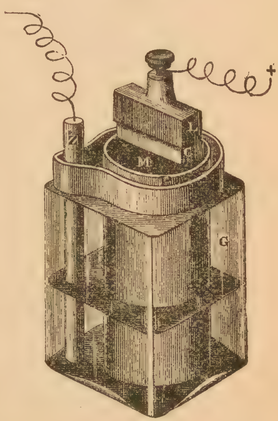
This style of battery has an E.M.F. of about 1.8, and is useful where a constant current is not required. The liquid soon becomes exhausted, crystals of chrome alum form, and the battery wants a rest, after which it again acts.

$$\text{The elements are} \begin{cases} \text{C plate, movable Zn, C plate.} \\ \text{Electropion.} \end{cases}$$

Describe the Leclanché cell.

Here Zn and a sol. of sal ammoniac act as the exciting agents, and peroxide of manganese is the depolarizer (Fig. 118). A rod of C (C) is tightly packed in a porous pot with a mixture of equal parts of MnO_2 and gas carbon covered with pitch. The C plate projects and constitutes one electrode. Outside all this is a glass vessel about one-third full of a strong sol. of NH_4Cl, about 6 oz. to the quart. In this is the + metal, a rod of Zn. The reaction is $Zn + 2NH_4CL = ZnCl_2 + 2NH_3 + H_2$. The MnO_2 gives off O_2 slowly, and the H_2 bubbles pass through the porous cup and form water with the O_2. $2MnO_2 + H_2 = Mn_2O_3 + H_2O$.

FIG. 118.



This sal ammoniac solution seems able to "crawl," from the porosity of the C plate, and forms local currents at its binding-screw. This may be mostly prevented by soaking the plate before use with melted paraffin, which prevents the capillary action.

The above style is the *Disque:* a more recent one is the *Prism* or

Gonda, where the porous cup is dispensed with, and the C plate is bound between two flat prisms made of the double chloride of iron and ammonia, mixed with MnO_2 and graphite. Either form has an E.M.F. of 1.48 volts, emits no noxious fumes, and can stand a T. of —16° C. They are not suited for electro-plating or closed telegraphic circuits, but are used in France altogether for open circuit work where there are intervals of rest. Cells have been used nine years without renewal of zincs, and only one renewal of sal ammoniac. They are useful for ringing bells and burglar alarms.

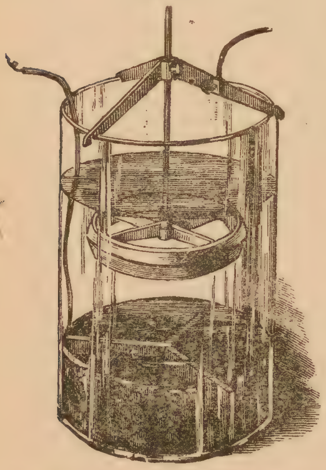
$$\text{The elements are (Disque form)} \begin{cases} Zn + NH_4Cl. \\ \text{Porous cup.} \\ C + MnO_2. \end{cases}$$

There is also the Law cell and Diamond-Carbon cell as modifications of Leclanché's.

Describe a gravity cell.

This variety, again, dispenses with the porous cup, and the two fluids are kept separate by the differences of sp. gr. Fig. 119 represents the form known as Callaud's. Cu is placed in a sol. of $CuSO_4$ at the bottom of the vessel, and Zn is suspended in dilute H_2SO_4 near the top. At first water is poured upon the vitriol crystals, and to start the action a little common salt or H_2SO_4 has to be added to the Zn; then $ZnSO_4$ gradually forms and floats on the heavier $CuSO_4$ sol. The reaction is just as in Daniell's cell: metallic Cu is deposited on the Cu plate. The separation of the two fluids is never complete; some of the Cu sol. rises and deposits copper on the zinc, and so neutralizes the elements. This is a very economical and constant battery, and is much used in this country for telegraphy.

FIG. 119.



The E.M.F. is about 1 volt.

What is the silver-chloride cell?

This cell, also known as De la Rue and Müller's, has come into quite general use for hospitals and physicians from its compactness and efficiency. It is of the test-tube shape and size, the tube being closed by a paraffined stopper, perforated to admit the electrodes. The tube contains a weak sol. of NH_4Cl (23 to 1000), in which is placed a rod of pure Zn, and also a silver wire which is embedded in about ½ oz. of AgCl contained in a cylinder of parchment paper. The latter is the depolarizer. The H and the NH_3 gases unite with the AgCl and reduce it to metallic silver, reforming NH_4Cl; thus:

$$Zn + 2NH_4Cl = ZnCl_2 + 2NH_3 + H_2;$$
$$2NH_3 + H_2 + 2AgCl = 2NH_4Cl + Ag_2.$$

A battery has been constructed of over 14,000 of these cells. The E.M.F. is 1.03 volts.

What is the sulphate-of-mercury battery?

This is used for medical pocket batteries, and consists of two or more small Zn — carbon cells, each 1 in. square and ½ in. deep. The C is placed at the bottom of a hard-rubber cup, and the Zn, resting on a ledge, forms the cover. A few grains of bisulphate of Hg to the teaspoonful of water are placed in the cups, and the acid of the bisulphate unites with the Zn, setting Hg free, which amalgamates the Zn. $2Zn + Hg(SO_4)_2 = 2ZnSO_4 + Hg$.

Describe Zamboni's dry pile.

In dry piles the liquid is replaced by solid hygrometric substances, as paper or leather. 1000 or 2000 paper disks, coated on one side with tin-foil and on the other with peroxide of manganese, are closely compressed in a glass tube. Such a pile can ring a bell or give sparks, and has been adduced to prove the contact theory of voltaic electricity; but chemical action is probably present, caused by dampness in the paper.

Two cells are used as standards—Daniell's and Clark's. The latter is very constant, and has a — plate of Hg covered with a paste of $Hg_2(SO_4)_2$ and $ZnSO_4$. A Zn plate rests upon the paste.

What is the comparative strength of the different cells?

The E.M.F. of a Smee cell is .65 volts.

17

The E.M.F of a	Clark standard	cell is	1.436 volts.
"	Daniell	"	1.072 "
"	Leclanché	"	1.48–1.60 volts.
"	Grenet	"	1.80–2.3 "
"	Bunsen	"	1.96 "
"	Grove	"	2 "

This means it would require 200 Smee cells to equal 65 Grove cells.

Compare voltaic with statical electricity.

There are no currents in statical electricity; in dynamical there is a constant source. The former is under enormous tension; the latter has but little.

A battery of over 8000 AgCl cells gave a spark of only $\frac{1}{3}$ in. in ordinary atmosphere. Statical electricity has little quantity; we could get more electricity for decomposing purposes out of a voltaic cell the size of a percussion cap than we could out of an electrical machine in fifteen minutes.

There is no economy in electricity from a galvanic battery as a substitute for steam—a use of zinc instead of coal. The latter has six times as much energy. 1 lb. of coal when burned can produce 6,000,000 ft.-lb. of work, and 1 lb. of Zn 1,000,000 ft.-lb. Zinc only gives up part of its energy when burned, and further oxidation could occur.

$$ZnO + C = Zn + CO;$$
$$CO + O = CO_2.$$

Zinc costs 25 times as much as coal, so the total is 125 to 150 times more expensive.

Engines only give back 20–25% of total energy, and with electrical machines we can recover about 85%; but with ideal arrangements in both zinc costs 40 times as much as coal. So electricity from a battery comes in for occasional use; electricity produced by steam is economical.

What are the electrical units? Compare them with similar terms used in speaking of water.

The electro-motive force is independent of the size of the plates, and depends on the number of cells and the nature of the substance used.

The E.M.F. of a large cell is no greater than that of a small one of the same kind. It corresponds to pressure or head in water, and its unit is one *volt*, which is about the pressure of a *gravity-cell*, or $\frac{11}{12}$ that of a *Daniell's cell.*

The *quantity* is the amount of electricity developed by any source: it depends on the extent of surface of the zinc: the larger the zinc, the greater the quantity. Quantity and intensity are not quite the same: the intensity is a part of quantity, and is the amount that can flow from the fountain-head in a unit of time.

The unit of quantity with reference to time is one *coulomb*, and that amount of electricity will deposit .001118 gm. of Ag. per. sec., or will set free .0000105 gm. of H per sec. A stream of water might be described by stating the number of quarts which flow through a given pipe per sec., and so an electric current may be estimated by stating the number of coulombs passing through a conductor in a second.

Strength of current is the quantity of electricity which flows across any section of the circuit in 1 sec. When the quantity passing is 1 coulomb per sec., the strength of current is 1 *ampère.* A current of 10 coulombs has a strength of 10 ampères; so the ampère is the unit of current strength; it does not refer to the energy of the current. It is also the strength produced by an E.M.F. of 1 volt through a resistance of 1 ohm. A milliampère is the thousandth part of this.

A coulomb may also be defined as the quantity delivered by a one-ampère current per sec. There is no unit analogous to the ampère for measuring liquid currents.

The *resistance* is the hindrance offered by a conductor to the passage of a current. It is comparable to friction or obstacles in the way of a liquid current. The unit is 1 ohm, and the legal ohm is represented by the resistance offered by a column of pure Hg 1.06 metre high and with a cross-section of 1 sq. millimetre, or it is about the resistance of a copper wire $\frac{1}{20}$ in. in diameter and 250 ft. long. 1 volt sends 1 ampère through 1 ohm in 1 sec. To express multiples and submultiples the terms megohm and microhm are used.

The *farad* is the unit of *capacity*, and is such an amount that in a condenser of 1 farad capacity the quantity of 1 coulomb produces a difference of potential of 1 volt. This is a very large unit, as the

capacity of the sun does not amount to 1 farad. A millionth part of this, or the microfarad, is a more practical unit.

A Leyden jar with a total coated surface of 1 sq. metre and the glass 1 mm. thick has the capacity of $\frac{1}{55}$ microfarad. This unit corresponds to the cubical contents of a reservoir for water.

The *watt* is the unit of energy, and represents the work done by 1 ampère when impelled by 1 volt. It is thus a *voltampère:* $W = C \times E.M.F.$ This amount of energy per sec. is $\frac{1}{746}$ of an English horse-power. It is analogous to the energy of a liquid current which is obtained by multiplying the weight of water falling by the distance it falls.

The *joule* is the unit of heat, and is the amount of heat, in calories, produced by a current of 1 volt in potential and 1 coulomb in quantity (*volt-coulomb*).

SUMMARY OF UNITS.

Electro-motive force, E.M.F., is measured in volts.		
Quantity of electricity,	"	coulombs.
Strength of current, C.	"	ampères.
Resistance, R.	"	ohms.
Capacity of a condenser,	"	farads.
Energy of current,	"	watts.
Work changed to heat,	"	joules.

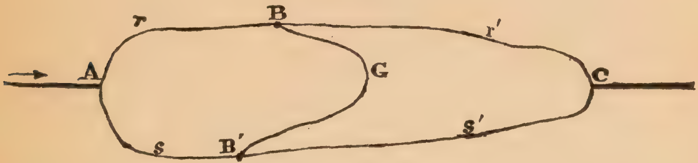
What are some of the instruments used for determining these units?

The *rheostat* is an instrument by which the resistance of a given circuit can be increased or diminished without opening the circuit. The water rheostat introduces the resistance of water into the circuit: some change the length of a wire introduced, others employ *resistance-coils.* These are made of German silver wire, which has high resistance and is calibrated for a certain number of ohms' resistance. It is wound double to neutralize any outside induction. These coils, from .01 to 100 ohm resistance, are placed in a resistance-box and attached to its cover. Holes are in the cover, one between each coil, and when these are occupied by copper plugs a current can pass through the cover without resistance. Remove a plug, and the current has to pass through a coil in order to get around the hole. These are more accurate than rheostats.

What is the Wheatstone bridge?

This is an instrument for measuring an unknown resistance by comparison with a known resistance (Fig. 120). Let two conductors

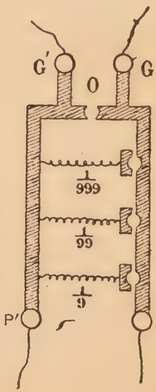
FIG. 120.



whose resistance is known, A B and B C, be connected end to end with the poles of a battery, and let these ends, A and C, be also connected by another conductor, A B′ C. A current must then pass by each of two paths. For every point in A B C there is a point in A B′ C, which has the same potential. At G is a galvanometer. Let one end of its wire be fixed at B. The point B′ which has the same potential on A B′ C can be found by shifting B′ toward A or C till the galvanometer shows no deflection. No current is passing through B G B′. Let the resistance of the four wires be r, r', s, and s', and it follows that $r : r' = s : s'$.

Suppose an unknown resistance be introduced at B′ C; then we must place known resistance-coils between A and B′ to bring the needle back to normal. Three terms of the above proportion are known, and the fourth or s' can be found.

FIG. 121.



Illustrate the use of shunts.

The principle of divided circuits is seen in *shunts*, where any proportion of a current may be transmitted through a galvanometer (Fig. 121). They consist of a set of resistances, $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$ that of the galvanometer. G and G′ are connected with the galvanometer, P and P′ with the battery. The gaps O, A, B, C can be closed by plugs, and these resistances be introduced. If all are open, the entire current passes through the galvanometer. By

plugging O, none passes through the galvanometer; by plugging C, $\frac{1}{10}$ passes G′. If resistance is $\frac{1}{9}$, the current at C is represented by 9, and that through G′ by 1, or $\frac{1}{10}$ of the whole. So the observed currents must be multiplied by 10, 100, and 1000 respectively to get the principal currents, as the current is inversely as the resistance.

CHAPTER XXVI.

DETECTION AND MEASUREMENT OF VOLTAIC CURRENTS.

What are Oersted's experiment and Ampère's rule?

Magnetic effects are most suitable for measuring and ascertaining the existence of voltaic currents. Oersted's experiment (1819) was that by which it was found that a fixed current has a directive action on a magnetic needle. Place a current in the magnetic meridian and let it pass over a needle. The needle will tend to take up a position which is more nearly at right angles to the magnetic meridian in proportion as the current is stronger. There are four ways for the current to pass: above or below the needle, and from N. to S. or S. to N. Ampère has given a simple rule by which we may remember in which way the needle will be deflected. *Personify the current, and the north end of the needle will always be deflected toward the left*—*i. e.* if we imagine ourselves swimming *in* the current and *with* the current, and *always* facing the needle, its north pole will turn to our left.

Describe the galvanometer.

The *galvanometer* or *multiplier* or *rheometer* is a delicate apparatus to determine the existence, direction, and intensity of currents. To understand the principle, let us suppose a magnetic needle is suspended by a silk thread and surrounded in the plane of the magnetic meridian by a Cu wire *m n o p q* (Fig. 122). When a current passes it will be seen that a swimmer lying in it and facing the needle will always have his left hand turned toward the same point of the horizon, indicating the deflection of the north pole of the needle.

The action of the current passing above and beneath the needle has been multiplied. Should there be several currents—*i. e.* a small coil of wire around the needle—the action is more multiplied and the

FIG. 122.

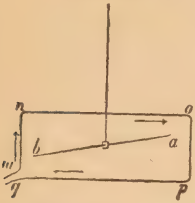
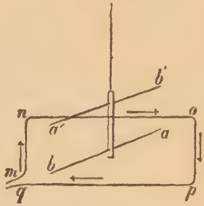


FIG. 123.



deflection increases. To get rid of the directive action of the earth on the needle an astatic system is used (Fig. 123), and the action of the current is now the only agent of deflection. The complete instrument is seen at G in Fig. 48. A brass plate revolves upon one beneath it, supported by levelling screws. Inside the glass case is fixed a Cu frame on which is wound the coils of insulated Cu wire, surrounding one needle of the astatic system, the upper one being alone visible. Over the frame is a graduated circle marked to 90° on either side of a 0 point. The length and diameter of the wire vary with the purpose for which the instrument is used.

There are long-coil and short-coil galvanometers. 30,000 turns of wire may be used for very delicate experiments.

Thompson invented a marine galvanometer not affected by the pitching of the ship. The indicator is a spot of light deflected to one side or another according to the direction of the current.

What are the tangent and the sine galvanometers?

With the usual galvanometer there is no law connecting current-strength with the deflection of the needle. A tangent galvanometer is based on the principle that the intensity of the current is directly proportional to the tangent of the angle of deflection. In the centre of a vertical Cu ring 12 in. in diameter is a short magnetic needle. The ends of the circle are connected with the current to be tested, and the value of the deflection of the needle is obtained from a table of natural tangents. This is adapted for currents of low potential. Another form, the sine galvanometer, is used for powerful currents.

Discuss Ohm's law.

Ohm proved that the strength of the current is inversely as the resistance and directly as the E.M.F. As generally expressed, *the strength of the current is equal to the electro-motive force divided by the resistance.* $C = \frac{E}{R}$. From this law all electrical calculations are made.

The resistance of a conductor depends on three factors: (1) its conductivity; (2) its section; (3) its length.

Each substance has its own peculiar conductivity. The smaller the section, the greater the resistance; the greater the length, the greater the resistance. So the strength will be inversely as the length, and directly as the section and conductivity.

In an ordinary cell there are two resistances to be considered: (1) that offered by the liquid conductor between the two plates, the *internal resistance*, or R; and (2) that offered by the conductor which connects the two plates outside the liquid, the *external resistance*, or r. Ohm's formula now reads $C = \frac{E}{R + r}$.

Internal resistance also depends upon the above factors, being greater as the distance of the plates apart is greater, and decreasing as the area of the plates submerged increases.

$$R = \frac{\text{distance of plates apart (length)}}{\text{areas of plates submerged (section)}}.$$

What is the strength of current where $E = 100$ and R the total resistance $= 1000$? $C = \frac{100 \text{ volts}}{1000 \text{ ohms}} = 0.1$ ampère.

The resistance of the human body is about 1000 ohms. If we increase the battery force to 1500 volts, then $C = \frac{1500}{1000} = 1.5$ ampère, which is fatal.

The E.M.F. of a Bunsen cell is about 1.8 volts, and its internal resistance $R = 0.1$ ohm. Connect the poles with a short thick Cu wire, so as to eliminate external resistance, and we have

$$C = \frac{E}{R + r} = \frac{1.8}{0.1} = 18 \text{ ampères}.$$

If any number of similar elements are joined together—*e. g.* 6—

there is 6 times the E.M.F., also 6 times the internal resistance. If we "short circuit" the current, r may be neglected, and $C=\frac{6E}{6R}=\frac{1.8\times 6}{0.1\times 6}=\frac{10.8}{0.6}=18$ ampères; *i. e.* a battery of several elements produces in this case no more effect than a single element. This is when it does no work.

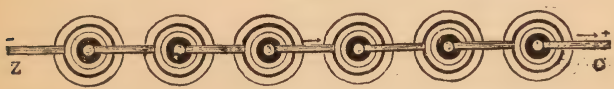
By giving it work, and calling the external resistance 1 ohm, $C=\frac{1.8 \text{ volts}}{0.1 \text{ ohm}+1 \text{ ohm}}=\frac{1.8}{1.1}=1.63$ ampères, a marked decrease from the 18.

Let 6 cells work, then $C=\frac{1.8\times 6}{(0.1\times 6)+1}=\frac{10.8}{1.6}=6.75$ ampères. So 6 cells do not give 6 times the current that 1 cell does—about 4 times as much. We may say, however, that the strength is proportional to the number of elements when the external resistance is very great, as in a telegraphic circuit, and where the internal resistance may be disregarded.

In what ways may cells be arranged in battery formation?

There are two principal ways, known as *series* and *parallel*—series for *intensity*, and *parallel*, *multiple arc*, *side by side*, for *quantity*. In the parallel or abreast method (Fig. 125) all the zincs are joined together and all the coppers, thus forming a single large cell. The E.M.F. is not increased, for this depends on the nature of the substances used; but the internal resistance will be 6 times less, for this factor is diminished by increasing the size of the

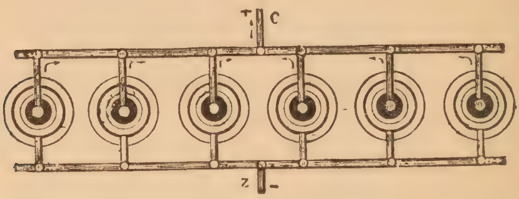
FIG. 124.



liquid conductor. Instead of using large plates, which would be inconvenient, we may connect similar plates. In this method the numerator of the fraction $\frac{E}{R}$ remains the same, but we decrease the denominator. This gives *quantity* at expense of intensity, and is the proper arrangement where the quantity required is large and resistance low, as in electro-plating.

Now, instead of allowing the current to pass directly out of each cell, as in Fig. 125, if it goes through another cell, as in Fig. 124,

FIG. 125.



we might expect that either the two cells would counteract each other or else double the E.M.F. The latter is true, and the E.M.F. is practically proportional to the number of cells connected in *series* or *tandem*. In hydrostatics the liquid pressure in six tubes of the same size, placed side by side and connected with a horizontal tube at the bottom, is only the same as that in any one of the tubes alone. But if the six are joined end to end in a vertical series, the pressure is six times as great. So by this latter arrangement we have *intensity* at the expense of quantity, the internal resistance being increased sixfold. The series method is the one for a long telegraph line or electric lighting, where there is high resistance, and intensity must be great enough to overcome it.

Let $E = 1$ volt, $R = 5$ ohms, and $r = 200$ ohms, and let 10 cells be connected abreast:

$$C = \frac{1 \text{ volt}}{(5 \times \frac{1}{10}) + 200} = .0049 \text{ ampère.}$$

We multiply 5 by $\frac{1}{10}$, because R varies inversely as the size of the liquid conductor.

By series method, $C = \frac{1 \times 10}{(5 \times 10) + 200} = .0400$ ampère—more than 8 times as strong as the abreast method. Here R is increased tenfold, as the current has to pass through 10 cells.

Combinations of the above methods may be used, two series of three cells each may be joined in parallel, or three series of two cells each. There are four ways for arranging six cells, and six combinations for twelve cells. In all of them the product of the current

strength in ampères by the E.M.F. in volts must remain the same, since each factor varies inversely as the other.

What are the qualities of a perfect battery?

1. High E.M.F.;
2. Constant E.M.F.;
3. Small and constant internal resistance.

No battery fulfils all these conditions.

The cost of the battery, the use to which it is put, and the trouble of keeping it in order determine which of these qualities shall be given up.

What are the accessory parts of a large battery?

Galvanometer, rheostat, induction coil and interrupter for Faradic current, current selector, selector for number of cells in circuit, communicator for changing poles, rheophores for attachment of electrodes.

CHAPTER XXVII.

EFFECTS OF CURRENT.—ELECTRIC LIGHTING.—ELECTROLYSIS.—ELECTRO-METALLURGY.—STORAGE BATTERY.

What are the effects of the current?

1. Physiological;
2. Heating;
3. Luminous;
4. Chemical;
5. Inductive;
6. Mechanical.

What are the physiological actions?

Protoplasm seems to have the general power of contracting upon the application of a voltaic current. On opening and closing the circuit which courses a muscle, a contraction will result. By very rapidly interrupting the current the muscle can be thrown into a state of physiological tetanus.

Muscles have natural electrical currents or *currents of rest.* A muscular contraction is accompanied by *heat*, *sound*, *change in shape*, *chemical change*, and *electrical change.*

The influence of a current on nerves is to throw them into a state of activity, and, depending on their functions and endings, a pain may be produced, a flash of light, or a sense of taste. Living nerve-tissue is found to have a certain electro-motive state, parts being electro-positive to other parts. On passing a current the alteration of its natural electro-motive condition is called *electrotonus.* The condition of the nerve close to the + pole or anode is called *anelectrotonus;* that near the — pole or kathode is *kathelectrotonus.* The excitability of the nerve is diminished in the former region and increased at the latter. According to the strength and direction of the current there are certain laws of contraction at the making and breaking. These facts are taken into account in the scientific application of electricity for medical purposes.

The movement which causes Venus's fly-trap, a carnivorous plant, to enclose an insect is accompanied by an electrical current.

Describe the heating effects of the current.

These effects depend on the conducting power of metals and strength of the current. A short thin wire, having great resistance, will become heated or incandescent. Edison got his first idea of the electric light from this fact. With a powerful battery all metals are melted. Cu has not been fused, but has been softened, so that two rods could be welded together. Mines are fired or blasts exploded by heating small resistant wires which are surrounded by the explosive. Surgically, galvano-caustic instruments are useful. A platinum wire heated to 600° C. removes tumors without hemorrhage, and at 1500° C. it cuts like a knife.

Another application is in *safety-plugs*, which are strips of lead interposed in strong currents, as from a dynamo. They are of such size that a current of certain strength will melt them, and so break the circuit; a current cannot thus exceed a certain limit.

What are the laws of heating effects?

There is always resistance to a current; otherwise when once started it would remain in motion for ever. If there is no external resistance outside the dynamo, heat is generated within it.

The laws of heating effects are determined by a *galvano-thermometer:* electric wires enter a vessel containing alcohol in which is placed a thermometer. The following law is established: *The heat*

disengaged in a given time is proportional directly to the square of the strength of current and to the resistance. This is known as Joule's law, and is expressed $H = C^2Rt$. $C^2 =$ ampères, $R =$ ohms, $t =$ seconds.

It is found that when a given weight of Zn is dissolved in H_2SO_4, a definite measurable quantity of heat is always produced—an exact relation between heating effect and the work of a battery.

What is the importance of electric welding?

Since 1886 this application of electricity has been highly developed by Prof. Thomson. It consists in uniting pieces of metal by pressing them together, end to end, and heating the juncture by an electric current: only so much of the metal is included in the circuit as is necessary for this purpose. The alternating current from a dynamo is employed and applied by a special machine, the *welder.* An E.M.F. of only about 1 volt is used, but an immense quantity of about 16,000 ampères. The pieces to be welded are rounded, so that contact is first made in the centre. Time required is 1 to 2 sec. for fine wires, and 2 to 3 min. for heavy bars. The range is almost unlimited, embracing welding hitherto considered impossible. Cast iron, Cu, Pb, Sn, Zn, brass, German silver, or bronze can be welded, each to its own kind or any one to any other one. Welds by this process resist the severest tests and are approved for strength and tenacity.

Describe some of the luminous effects of the current.

Brilliant sparks are seen when the two terminals of a battery are brought together or separated. Metal terminals in strong currents even diamonds melt like tallow; so the best results are obtained with carbon terminals, which are less fusible.

There are two kinds of electric light: (1) the *arc*, and (2) the *incandescent.*

Describe the arc light.

The electric light was discovered by Sir Humphrey Davy in 1801, but could not be utilized for seventy years, until electricity could be cheaply produced. Let two carbons be in contact until they are incandescent, and then, if they are removed about $\frac{1}{10}$ to $\frac{3}{8}$ in., according to the current, a luminous arc will extend between the two. The

charcoal wears away on the + pole, making a crater, and is heaped upon the — pole, making it pointed. The + pole is the hotter, about 2400°–3900° C., and most of the light comes from the tips of the carbons. The + pole wears away about twice as fast as the — one, and in the usual lamps of New York about 2 long C sticks are used up in one night.

Gas graphite is used, as it burns slowly in air, otherwise a vacuum would be necessary. The arc is not formed of sparks, but of incandescent particles of carbon; its color and shape depend on the nature of the conductors. Its length is much greater in a partial vacuum: it is attracted by a magnet. 40 or 50 volts at least are necessary for a small arc light. Two dynamos and an engine will cost about $6000, and will supply 260 lamps with 16 candle-power. The running expenses are about the same as for gas.

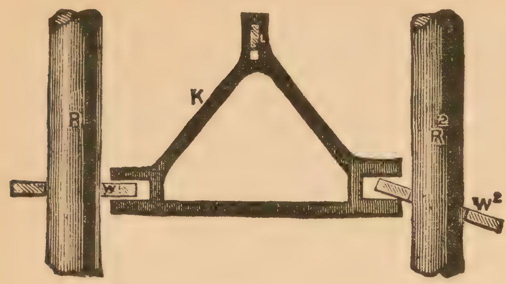
Describe some of the regulators of the electric light.

The great difficulty is to keep the carbons at a proper distance, else the light goes out or varies in intensity. They must be automatic. The use of broad carbons partly obviates the difficulty. Wheels of C have been tried. Alternating currents may be used, which change the direction of the waste. One carbon may be placed on a cylinder floating in glycerin, its base connected with a cup of Hg. The float rises slowly as its C wears away, and it may be regulated by weights.

The chief ways are by a *train of clockwork operated by an electro-magnet and by solenoids.* (See p. 286.) The first was invented by Foucault, and has received various improvements. The carbons are attached to brass rods supported vertically and connected with the clockwork. When they are in contact or too close, the strong current which passes through the electro-magnet attracts the armature operating the clockwork, and separates the carbons in opposition to a weight or spring which tends to bring them together. As the current producing the separation becomes weakened by the increased resistance of the arc, a balance is struck between the opposing forces.

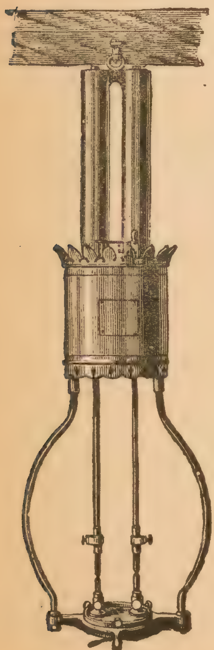
The *solenoid* method is used by Siemens, Brush, and others. Here the upper carbon-holder is moved against gravity by an armature to which it is attached, K (Fig. 126). This armature moves

FIG. 126.



vertically in the centre of a solenoid coil through which the current passes. As it is attracted upward, a clutch on its side grips the edge of a loose washer, and that lifts the carbon-holder, R^1 or R^2. Fig. 126 shows this, and Fig. 127 shows its application to a double-carbon lamp. The clutch on the left is narrower than the one on the right, so the left pair are kept apart till the right ones are consumed, when the change of resistance brings the left pair into contact.

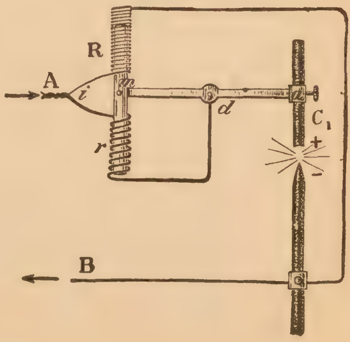
FIG. 127.



Describe Hefner von Alteneck's regulator.

This regulator is of the solenoid variety, and is used in the Brush light. It is of import-

FIG. 128.



ance in arc-lighting in general, and consists of a shunt current which opposes or partially neutralizes the main current (Fig. 128). The current from A to B divides at i, the main branch going through a low-resistance coil r and the lamp, while a shunt current carries off about 1 % of the whole current through a high-resistance coil R and around the lamp. The armature m is drawn down by the greater induction of the lower current, which separates the carbons. This increases the resistance of the arc, and more of the current passes through the shunt. Since the resistance in R is constant, the strength of its current is increased in the same ratio that r is diminished. This tends to draw m upward, shortens the arc, and adjusts it to its normal length.

What is the Jablochkoff candle?

This was one of the early devices, and does away with the necessity of regulators. Two carbons are placed side by side, separated by a thin insulating septum of kaolin or plaster of Paris. A bit of carbon connects the upper ends of the rods to start the current across as it passes up one rod and down the other. The kaolin is melted, and wastes away like the wick of a candle in proportion to the waste of the carbons. As the + pole wears away twice as fast as the — one, alternating currents are used; *i. e.* the commutator on the electrical machine is omitted.

What may be said of the properties and intensity of the electric light?

It has chemical effects similar to those of solar light. It gives the solar spectrum, but has several very bright lines, their color depending on the metal used.

The intensity from 48 Bunsen cells is equal to 572 candles. The most powerful arc equals 55,000 candles. Schwendler has devised for electric lights a new unit of luminous intensity, called the *platinum-light standard.* It is the incandescence produced by a current of known strength passing through a U-shaped strip of platinum-foil 36.28 mm. long, 2 mm. wide, and 0.017 mm. thick. The same amount of light can always be reproduced.

The international standard, adopted in 1884, is the light emitted by a sq. cm. of melted platinum when on the point of solidifying.

Describe the incandescent lamp.

The light here depends upon some sort of fibre heated red hot and placed in a vacuum, for C is volatilized at high T. in oxygen. Edison invented these filament lamps. Pt was first employed, but the heat required was just below its melting-point, and the world's supply of Pt would not be sufficient for lighting New York City. Carbon has 250 times the resistance of Pt, but has less resistance hot than when cold. So Edison next used pasteboard and tissue-paper carbonized. He finally found bamboo-fibre from Japan. These fibres are placed between nickel plates and put into a muffle, and are changed to C. The size of the fibre is that of a hair, and the shapes are various.

The Maxim fibre has the shape of the letter M, is first carbonized by baking without air, and is then heated in coal gas, called *flashing*, which deposits C and builds up the fibre to uniform calibre.

Again, gun-cotton dissolved into collodion may be denitrated, and becomes structureless and homogeneous cellulose. It is soaked in ammonium sulphide, cut up into fibres, and made almost metallic by being carbonized. Though there is no combustion in the filaments, they usually break after a life of 600 to 1000 hours. They are attached to platinum terminals sealed into a globular glass bulb, so shaped as to better resist atmospheric pressure. A vacuum is produced of $\frac{1}{1000000}$, on the Sprengel air-pump principle. Air-pumps had to be perfected to make electric lighting a success.

The current may be direct or alternating, but must be steady. Can sometimes see the fluctuations of the engines by watching the lights. An Edison lamp of 16-candle power requires a current of 0.6 ampères, and has a resistance of about 170 ohms. Common gas produces 15 times as much heat as electric light, and vitiates the air. Electric lamps require no air, make no heat, create no combustion.

Can get four times more light out of kerosene or coal gas by putting them into electricity. Burning them is wasteful.

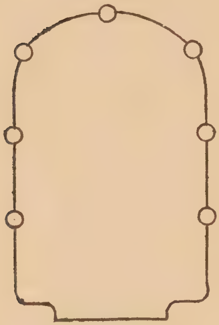
How are arc and incandescent lamps distributed?

The arc lights require currents of 10 to 15 ampères, and the series distribution is most economical, the entire current passing from lamp to lamp (Fig. 129). Any variation in the resistance affects every lamp in the series, and the extinction of one will interrupt the cur-

18

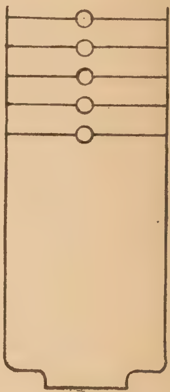
rent and cause the extinction of those beyond. This is obviated by *automatic cut-outs*, constructed on the principle of Hefner von Alteneck, and the full current is carried past an extinguished lamp.

FIG. 129.



Dynamo.
Series.

FIG. 130.



Dynamo.
Parallel or Multiple Arc.

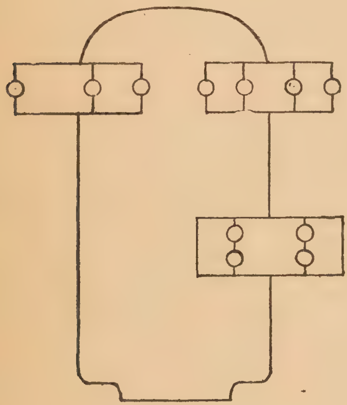
For incandescent lamps the *parallel* system is best (Fig. 130). Two heavy copper mains issue from the dynamo, between which the lamps are mounted on fine wires, taking off the current according to conductivity. Or a number of short series of lamps may take the place of single lamps on a parallel circuit; this arrangement is called *multiple series* (Fig. 131). Again, groups of lamps in parallel may be placed in series, called *series multiple.*

Edison has a 3-*wire system*, where two parallel circuits and two dynamos are combined. A single central main takes the place of the two interior mains; this is neutral, while of the others, one is + and one — (Fig. 132). When an equal number of lamps is lighted in each circuit, the entire current flows in the external mains and across through the several pairs of lamps. If more lamps are lighted on one circuit than on the other, this increases the current on that circuit, and this surplus current flows through the central main. Three mains thus do the work of four, and as the central one only carries the surplus current, it is found its cross-section can be reduced $13\frac{1}{2}\%$ below that of the other two.

What is the converter?

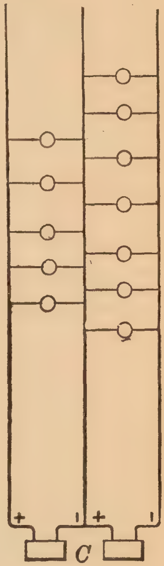
The incandescent light furnishes the chief employment of the alternating current. In the line of direct currents *resistance coils* are placed for the regulation of the supply; in the alternating circuit *converters* are used. A dynamo will supply perhaps 5000 incandescent lamps, and its current is of high potential and small quantity. This is required to be reversed at points where it is consumed, the lamps using a current of large quantity. The *converter* is simply a reversed induction coil. The primary coil consists of fine wire, which receives the high potential current from the dynamo, and the secondary coil consists of coarse wire, which means low resistance, and so a large current is induced and supplied to the lamps. These converters are distributed along the line mounted on poles or otherwise, and one will supply ten to eighty lamps.

FIG. 131.



Dynamo.
Multiple Series.

FIG. 132.



Dynamo. Dynamo.

What is Edison's standard for street lamps (arc)?

Three watts per candle-power is the standard. An E.M.F. of 115

volts and a current strength of 0.43 ampères will overcome a resistance of 267 ohms: $R = \frac{E}{C} = \frac{115}{0.43} = 267$.

The same current gives 49.4 watts; $W = C \times E = 0.43 \times 115 = 49.4$. Street lamps have about 16 candle-power $= \frac{49.4}{16} = 3.08$ watts per candle. The relation of voltage, candle-power, and current strength is here shown:

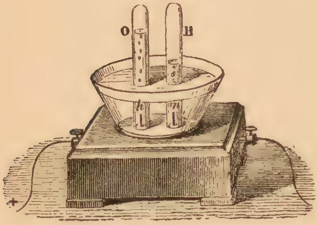
Volts,	96	98	100	102	104
Candle-power,	12	13.9	16	18.3	20.8
Ampères,	0.71	0.73	0.75	0.77	0.79
Life of C in hours,	2875	1670	1000	614	386

Chemical Effects of Current.

Define and discuss electrolysis.

Electrolysis is decomposition by the voltaic current. An *electrolyte* is a compound which may be resolved into its elements by this means.

FIG. 133.



The products of decomposition are *ions*, the kation and anion appearing respectively at the kathode (—) and at the anode (+).

Water was formed synthetically in 1781. It was first decomposed in 1800. In the bottom of a glass vessel fix two Pt electrodes p and n. (Fig. 133). Fill the vessel with acidulated water, as pure water is a poor conductor, and invert over the electrodes two glass tubes full of pure water. When this apparatus is interposed in the circuit of a battery, gas-bubbles rise from each pole. The volume of that liberated at the — pole is twice that of the other. The former is H, and the latter O. There is not quite the right proportion of H and O, as a little of each dissolves in water. O_3 and H_2O_2 are also liberated.

	Wt.	Vol.
H =	2	2
O =	16	1
	18	3

H and the metals are always found at the — electrode, and they are said to be electro-positive, unlike attract. Non-metals go to the + pole. O is the most electro-

negative element, and K the most electro-positive. Elements have been discovered by this means. Davy split up the alkalies potash and soda, and proved that they were oxides of hitherto unknown metals. Binary compounds are also decomposed, and a compound liquid is always split into two parts, though it may contain three or more elements.

When HCl is decomposed, C electrodes must be used, as Cl attacks Pt. If the Cl is liberated in an indigo solution, it will be bleached as the decomposition goes on:

$$-\begin{array}{c|l} H_2 & O \\ H & Cl \end{array}+$$

Salts in solution are decomposed, and the acid part goes to the + pole and the other to the —.

$$-\begin{array}{c|l} Na_2 & SO_4 \\ Cu & SO_4 \end{array}+$$

Alcohol, ether, and the essential oils cannot be decomposed.

What is secondary electrolysis?

The group SO_4 does not remain as such, but unites with water and forms sulphuric acid. The Na_2 does not exist as free Na, but decomposes water and gives secondary products; viz. H at the — pole and O at the other: this is secondary electrolysis:

$$\begin{array}{r|l|r|ll} & Na_2 & SO_4 & & O \\ H_2 \; H & OH & H & OH & + \\ H & OH & H & OH & \\ & 2NaOH & H_2SO_4 & H_2O & \end{array}$$

What are the laws and uses of electrolysis?

1. *Electrolysis cannot take place unless the electrolyte is a conductor and a liquid.*

2. *The energy of the electrolytic action is the same in all parts of the conductor.*

3. *The same amount of electricity decomposes chemically equivalent quantities; i. e. the weights of the elements separated are proportional to their chemical equivalents.*

The chemical equivalent is the atomic weight divided by the atomicity; is the smallest amount which can replace an H atom.

4. *The quantity of a body decomposed in a given time is proportional to the strength of the current.*

The uses of electrolysis are:

(1) To ascertain the constitution of chemical compounds;
(2) To obtain pure metals;
(3) To measure strength of current;
(4) To electrotype and electroplate;
(5) To make storage batteries.

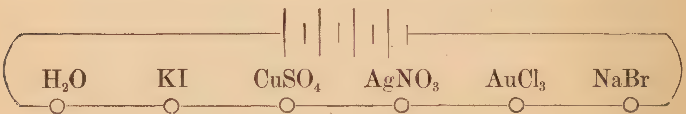
Illustrate the third law.

Decompose water, lead chloride, and tin chloride. It will be found that for every 18 parts of H_2O decomposed there will be liberated 2 parts of H, 207 of Pb, and 117 of Sn at the − electrodes, and 16 of O and 71 (2 × 35.5) of Cl at the + electrodes.

These numbers are proportional to the equivalents, and not at. wts., of those substances.

2 H	207 Pb	117 Sn
16 O	71 Cl	71 Cl
18 H_2O	278 $PbCl_2$	188 $SnCl_2$

Let a battery current pass through the following substances:



H 1	K 39	Cu″ 31.7	Ag 108	Au‴ 66	Na 23
O 8	I 127	O 8	O 8	Cl 35	Br 80

At. wt. of Cu is 63.4 ÷ 2 = 31.7.
At. wt. of Au is 197 ÷ 3 = 66.

For every part of H liberated, 108 parts by wt. of Ag will be dissolved, 39 of K, or 66 of Au. An increase in cells does not increase the amount decomposed.

Electrolysis proceeds according to equivalence; the same quantity that liberates 1 atom of a monad liberates half an atom of a dyad, and a third of a triad.

What is a voltameter?

From the fourth law is founded Faraday's voltameter. The intensity of the current is ascertained from the quantity of water which it decomposes in a given time. It consists of a glass cell in which the water is decomposed. This is connected with a flask containing water. The mixed gases expel the water from this flask, and the weight of the liquid expelled is a direct measure of the volume of the disengaged gases. The gases may also be passed directly into a graduated tube. 1 coulomb sets free .000010386 gm. of H.

The amount of current depends on the quantity of Zn dissolved. 32.44 parts by weight of Zn will be decomposed while one part of H is being liberated, or to liberate .000010386 gm. of H will require $.000010386 \times 32.44 = .00033692184$ gm. of Zn, and this number is called the *electro-chemical equivalent* of Zn.

Silver and copper voltameters are used, and the Ag or Cu liberated at the — pole is dried, washed, and weighed, and the weight is the measure of the current intensity.

What are the disadvantages of the voltameter?

It gives only mean intensity, and not strength for any given moment. As it offers great resistance, it is only useful for strong currents. It has to be corrected for pressure and T. Water absorbs the O, and also H slightly. O_3 and H_2O_2 are liberated and affect the result.

Magnetic measurements are preferable, are delicate, and give the intensity at any moment.

How is electric consumption measured?

Gas-lighting would have been a failure had not the metre been invented. Edison saw the same difficulty in electric lighting, and he uses chemical means, depending upon the amount of Zn dissolved. His voltameter contains a wire and Zn of such size as to offer $\frac{1}{1000}$ of the whole resistance. In it are two compartments containing Zn. The agent takes out one Zn every month, weighs, ascertains its loss, and computes the electricity used. The other Zn is left undisturbed for a year or so, to act as a check.

What is electro-metallurgy?

Electro-metallurgy or galvano-plastics is the art of precipitating

certain metals from their solutions by an electric current, either galvanic or one from a dynamo. The current must be one of large quantity. The art was discovered in 1839, independently by Spencer and by Jacobi. A mould has to be made, and on this is deposited a layer of the desired metal.

Describe electrotyping.

This book is printed from electrotype plates. A shallow pan is filled to the depth of 1 cm. with melted wax. A few pages are set up in type, and a mould is made by pressing this into the wax. Powdered graphite is applied to make the wax a good conductor of electricity. Flow the surface with alcohol to prevent adhesion of air-bubbles, and then with a solution of $CuSO_4$. Dust over it some iron filings, by which a chemical action is started. Next place the form in a bath of acid $CuSO_4$ and connect it with the — pole of a battery or a dynamo. From the + pole suspend a plate of Cu about 2 in. from the wax surface. The salt of copper is decomposed and its Cu is deposited on the mould. The acid formed at the + pole dissolves the Cu plate, and so keeps up the degree of saturation of the solution.

When the Cu film is about as thick as a visiting card, it is removed from the wax, and shows every line of the original. This shell is then backed with melted type-metal to give it firmness, is fastened to a block of wood, and then is ready for the printer. A small amount of type used over and over can thus do a large amount of printing. A quantity battery is necessary for the above purpose, a Daniell's or a Smee, but a dynamo of special construction is more commonly used.

Describe electro-plating.

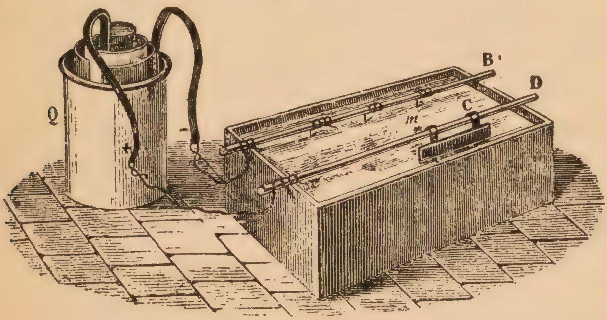
This process is practically the same as the one described above, only here the metallic coat remains permanently on the object.

The articles to be plated have to undergo certain preparatory steps called *buffing*, *cleansing*, *pickling*, and *scouring*. After this they must not be touched again by the hand, and they may now be placed in the plating bath suspended from the — pole of a battery. The bath used is always a solution of a salt of the metal to be deposited. From the + pole of the battery is suspended an anode, which

is a plate of the same kind of metal as that to be deposited. (See Fig. 134.)

The reason that the articles to be plated must be placed at the — pole, is that electrolysis goes on in the bath, and $CuSO_4$, for instance, and H_2O are decomposed. Metals like Cu and H are electro-positive, and go to the — pole, whereas the acid radicle SO_4 and O go

FIG. 134.



to the + pole. The SO_4 becomes SO_3, which unites with a molecule of water forming H_2SO_4 ($SO_3 + H_2O$) on the Cu anode, dissolving it somewhat, and so renewing the supply of $CuSO_4$. Or the SO_4 may unite directly with H_2. The film of plating comes from the salt in solution, and not directly from the metal anode.

The bath for *electro-silvering* is usually a solution of the double cyanide of Ag and K, formed from nitrate of silver and cyanide of potassium; thus,

$$AgNO_3 + KCN = AgCN + KNO_3;$$
$$AgCN + KCN = AgCN.KCN.$$

German silver makes a good base for being plated, or some metals have first to be covered with a layer of Cu, and then this Cu can be plated. 125 tons of silver are probably used annually for electroplating. The average deposit on forks and similar sized articles is 80 to 100 gm. per dozen.

The bath for *electro-gilding* is a solution of gold chloride and KCN.

Nickel-plating has now become very important. A layer $\frac{1}{1000}$ in. thick may be formed. Commercial nickel contains nitrate of sodium and HNO_3, and plating could not be done successfully till this impurity was gotten rid of: $\frac{1}{10}$ of 1% was fatal to plating. Adams took out the first patent not to do a thing—viz. not to allow the presence of nitrates. Temperature in india-rubber processes is patentable.

A plate of pure Ni is the anode, or one of Pt and $\frac{1}{3}$ Ni may be used, and salts of Ni and ammonium are in the bath. This makes an excellent plating for surgical instruments, but some say it is porous, as seen by the microscope, and so perhaps gives better lodgment for bacteria.

The time required for electrotyping is about 2 hours with a dynamo direct current, or 14 hours with a battery current; for silver-plating, 3 to 4 hours with a dynamo. Gold is deposited with great rapidity: a few minutes' immersion is sufficient. Nickel-plating requires 15 minutes to an hour with a dynamo.

Zn, Fe, steel, Sb, can all be deposited; when a film of the latter is broken, it becomes red hot, a peculiar molecular state. Copper plates can be *steeled* by an iron deposit of extraordinary hardness. In Ansonia, Conn., iron telegraph wires are coated with Cu; 15 tons per week are deposited. Many works of art can be reproduced; even copies of daguerrotypes may be made. Electro-etching can be done by attaching the article to the + pole, where it is eaten away.

Hg is said to be removed from a patient by making him the anode.

Other important applications of electrolysis are the *refining of metals* and the *reduction of ores*. Aluminium can now be obtained from its ores at a greatly reduced price. The process is Hall's, patented in 1889. A steel crucible lined with C contains a bath of the double fluoride of Al and Na and of Al and Ca. The bath is fused at a red heat, and Al_2O_3 is formed, dissolved in the bath. A dynamo then electrolyzes the alumina, but not the bath.

What is the principle of the storage battery?

When water is decomposed by Pt electrodes, O is condensed on the + plate and H on the — plate. The effect is to produce a current in opposition to the original one.

Grove has constructed a *gas battery* on this principle. Two tubes containing H and O are inverted in water. When the external circuit is completed, the gases recombine to form water, generating an electric current.

The products of electrolysis themselves form a battery. *The storage of electric energy by chemical decomposition is recovered by chemical recomposition.* This is the principle of the *storage battery*, the *secondary cell*, or *accumulator.*

Secondary electrolysis is produced (see p. 277) as in the decomposition of Na_2SO_4. There is no secondary action in the decomposition of HCl or HNO_3. The electrodes are not acted upon. $8HNO_3$ splits into $8NO_2 + 8O + 8H$. The 8H reunite with the acid, $8H + HNO_3 = NH_3 + 3H_2O$. When HCl is decomposed, $CuCl_2$ is formed at one pole, producing nothing for recombination.

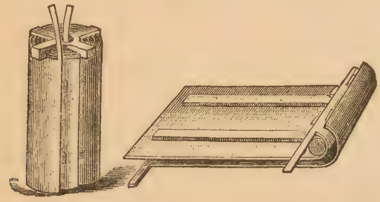
Describe Planté's storage battery?

When acidulated water is decomposed by lead electrodes, lead oxide will coat one and H will be occluded on the other.

		$-Pb$	$Pb+$	
$Pb + H_2$	H_2	SO_4 H_2	O	PbO_2

When the Pb plates thus acted on are connected, there is a recomposition of O_2 and H_2, and a new electric current in the reverse direction. The plates run down to plumbous oxide, PbO, on either

FIG. 135.



side, which is reduced to $PbSO_4$ by the acid. During the second charging this sulphate is decomposed and restored to the solution, and the leads are free to take up O and H again.

Planté's element consists of a broad strip of sheet lead provided with a tongue and laid upon a second similar sheet, contact being prevented by narrow strips of felt (Fig. 135). The sheets are rolled together, forming a compact cylinder, which is placed in a vessel of dil. H_2SO_4. The tongues of the leads are now attached to a battery, and the water decomposed, as seen above. When the anode has ceased to absorb O_2, the cell is disconnected, and then discharged by making external connection. This process is repeated many times during a period of several months, the object being to cover one plate with a thick coating of PbO_2 and the other with a coating of spongy lead. They are recharged each time with a reversed current, but when the plates are completed subsequent charging is always in the same direction.

What is the Faure cell?

Faure prepared plates by coating sheet lead with a paste made of red lead, Pb_3O_4, and sulphuric acid. The paste is kept in place by a sheet of parchment paper, by felt, or a blanket, and the plates are then rolled up and placed in a jar of acidulated water. Electrolysis with alternation of current is employed, by which in a few days the Pb_3O_4, called *minium*, is changed to PbO_2 on one plate and spongy lead on the other: the cell is now ready for practical use.

The *improved Faure cell* has the lead plates made in the shape of gridirons, and the openings are filled with a paste of Pb_3O_4 and H_2SO_4 for the + plates, and PbO or litharge and H_2SO_4 for the — plates. Each plate is electrolyzed separately before being combined in the cell intended for use.

The *Julien* cell has grids made of Pb, Sb, and Hg; the Pumpelly cell, from Chicago, has the plates horizontal, otherwise the same as the Faure cell.

The *uses* of storage batteries are for ringing bells, for turning small wheels, for incandescent or even arc lights, for propulsion of street cars, etc. One may be used for a week for lighting purposes, and the best cells have an E.M.F. of 2 to 3 volts. They can never be economical if charged by galvanic batteries; if done by dynamos, they will yield about 40% of the work transmitted to them. They store energy rather than electricity.

They were used on the Madison Avenue street-cars of New York, but have been abandoned. 120 cells per car were required, weighing 3600 lb., stored beneath the seats. Their alleged energy was sufficient to carry 400 people 36 miles.

The disadvantages of these batteries are—(1) loss of H_2SO_4 and increased resistance; (2) formation of $PbSO_4$; (3) plates unequally charged; (4) buckling and distortion of plates, rendering cell worthless. About three hundred patents have grown out of Faure's device. They may be useful in a small way, but not yet on a large scale. They are convenient for establishing stock companies.

CHAPTER XXVIII.

ELECTRO-DYNAMICS.—ELECTRO-MAGNETS.—TELEGRAPHY.

What is electro-dynamics?

By this term is meant the laws of electricity in a state of motion, the action of currents upon each other and upon magnets.

FIG. 136.

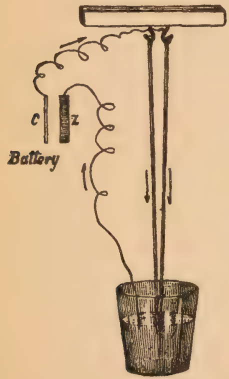
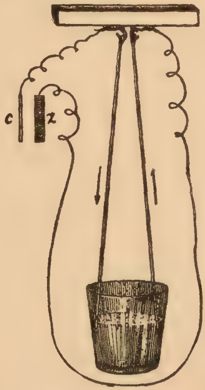


FIG. 137.



Electro-statics deals with electricity at rest. All the phenomena for parallel and angular currents follow three simple laws: 1. *Paral-*

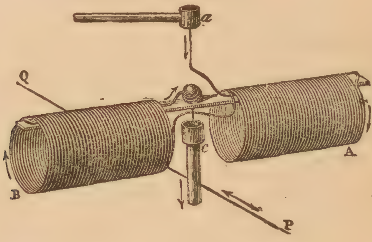
lel currents in the same direction attract one another. 2. *Parallel currents in opposite directions repel one another.* 3. *Angular currents tend to become parallel and flow in the same direction.*

An illustration of the first two laws is seen in Figs. 136 and 137, and also by what is known as *Roget's vibrating spiral.* It consists of a battery wire bent in the form of a spiral. One end dips into a dish of Hg, and the wire from the other electrode dips into the same dish. While the current passes it is parallel with itself in the spiral. Attraction follows, and one end of the coil is lifted from the Hg, and the circuit is broken. Gravity acts, the coil again touches the Hg, and rapid vibrations are produced.

Describe a solenoid.

To illustrate the third law a solenoid may be used. A solenoid is a system of equal and parallel circular currents formed of the same piece of insulated copper wire and coiled in the form of a helix or spi-

FIG. 138.



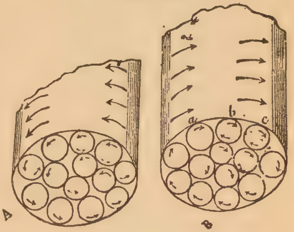
ral (Fig. 138). It is only complete when part of the wire passes in the direction of the axis in the interior of the helix. Let such a coil be movable about a vertical axis, or let it be supported by a little floating battery. Pass a rectilinear current Q P beneath it, and at the same time let a current pass in the solenoid. The latter will turn and set at right angles to the lower current; *i. e.* those currents in the lower parts of the coiled wires are parallel to, and in the same direction with, the current of the straight wire.

Explain the directive action of the earth on solenoids.

If a solenoid be supported as in Fig. 138, and a current be passed through it, it will move, and finally set in a position so that its axis

is in the magnetic meridian. In the lower half of the coils the current is from east to west; *i. e.* descending on the side toward the east and ascending on the west. A solenoid is thus directed like a magnetic needle, with a north and south pole, and fully illustrates Ampère's theory of magnetism. At the S. pole of a magnet or solenoid the currents are in the direction of the hands of a watch S: when the N. pole is looked at, the current is still east and west, but it seems to be in a direction opposite to that of the hands of a watch N (Fig. 139). Illustrate this to yourself by marking currents around a crayon of chalk. The Ampèrian theory has already been spoken of on p. 224. The earth itself is supposed to be traversed by such currents, explaining its magnetism. They pass from east to west beneath the earth, if that expression be allowed. These currents direct magnetic needles or solenoids according to the third law, that angular currents tend to become parallel and flow in the same direction.

FIG. 139.



Magnets and solenoids or two solenoids will mutually attract or repel each other, just as magnets themselves would do.

Electro-magnets.—Magnetization by Currents.

When a Cu wire traversed by a current is immersed in iron filings, they adhere to it, as to a magnet, as long as the current continues. Or if we coil an insulated wire about an unmagnetized steel bar, and then pass a current, the bar will become strongly magnetized; either galvanic or statical electricity will do it. The S pole of the new magnet will be that one where the wire was wound S, or if a person swimming in the current look at the axis of the spiral, the N. pole is to his left.

What are electro-magnets?

Electro-magnets are bars of soft iron which under the influence

of a voltaic current become magnets. This is only temporary magnetism, and ceases with the current. They are usually of horseshoe form, and an insulated Cu wire is rolled around the two branches in such a way that if the horseshoe were straightened out the wire would all be in the same direction. Soft iron wires are better than solid iron for the core. The iron should be as pure and soft as possible; otherwise it will acquire some magnetism and not respond readily to every change of current. This acquired magnetism is called *residual* or *remanent* magnetism.

The strength of the magnet is proportional to the strength of the current and number of windings, but independent of the width of the coils, of the nature or thickness of the wire, taking resistance into account.

On making or breaking the circuit around the soft iron the movement of its molecules in changing positions changes the shape of the bar, but not its dimensions, and produces *audible sounds.* Two are always distinguishable: one is musical, and the other a series of harsh sounds corresponding to the interruptions of the current.

Here was the first idea of a telephone, and an instrument made on this principle was used for years by Reis in Frankfort, and was called *telephone.*

What is the "suction of the coil"?

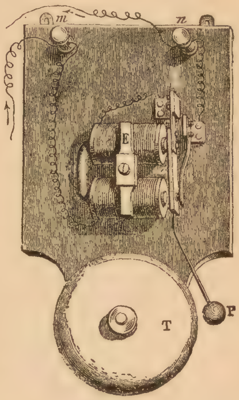
This is the attraction of the coil exerted on a movable soft-iron core. It is strongly drawn into the coil, and oscillates before becoming stationary. Page's engine (locomotive) depends on this principle, rapidly magnetizing and demagnetizing the soft iron which will move up or down, and its rectilinear motion can be changed into rotary by a crank. It can run 20 miles per hour, but at forty times the cost of an ordinary engine.

What are the uses of the electro-magnet?

Electric bells, fire- and burglar-alarms, electric printing-machines, and "tickers" all make use of the electro-magnet. The general way of its working is seen in Fig. 140. E is the magnet connected with one wire of the circuit, and the other wire is connected with spring C, which presses against the armature *a*. When the current

passes, the armature *a* is attracted, which carries with it the hammer P. The moment this takes place contact is broken between the armature and the spring, and the electro-magnet ceases to act. A little spring at the base of the armature brings it again into contact with C, and the current again passes.

FIG. 140.



In case of electric clocks a pendulum beating seconds opens and closes a circuit at each oscillation, and the armature will also beat seconds. This motion is conveyed to cogs and thence to the dial. A whole system of clocks as on a railroad line can thus indicate the same hour, minute, and second.

In the fire-alarm box you are directed to "pull down once and let go." This winds a spring which sets in motion a train of wheels, one of which has notches on its circumference corresponding to the number of the box; *e. g.* three notches together and four notches together. This revolving wheel touches a lever and closes a circuit, but as a notch passes under the lever the circuit is broken. This demagnetizes an electro-magnet at the central station and releases an armature which strikes a bell; thus 34 will be struck off. The spring is wound just enough to cause the wheel to revolve three times.

One form of an electric pen has an electro-magnet inside which will attract an armature beneath, and so prick holes in paper.

Electric engines, dynamos, and motors all depend upon the electro-magnet; not an economical means if Zn be used to obtain the power, but useful in the rapid transmission of small power to great distances, as in the electric telegraph.

The Electric Telegraph.

What is its history?

No one man ever invented the electric telegraph. Franklin in 1760 is said to have suggested something of the kind. In 1774, Lesage constructed the first one at Geneva, using statical electricity

—24 wires and 24 pith-ball electroscopes, one for each letter of the alphabet. Sömmering in 1808 first used voltaic electricity for this purpose, employing a water voltameter for each letter. In 1820, Ampère used 24 galvanometer needles.

In 1831, Prof. Henry really had the first telegraph, but never thought of using it as a commercial enterprise. He employed the electro-magnet and used a code of signals.

In 1833, Gauss and Weber used a single galvanometer needle, indicating letters by right and left deflections, and observed the oscillations by a telescope. Steinheil in 1836 or 1838 discovered that only one wire was necessary, the earth acting as a return wire.

Cook and Wheatstone in 1837 introduced the *needle* telegraph, and constructed on the London and Birmingham Railroad the first line ever employed for commercial use.

Prof. S. F. B. Morse, in 1835, invented a recording system of dots and dashes. His patent is dated June 20, 1840, and his claims have been used to the detriment of the others mentioned. He constructed the first line in the United States, between Baltimore and Washington, and sent the first message on May 27, 1844. He used two wires, and not one.

What are the essentials of a simple line?

(1) Battery; (2) conductor; (3) signal key or transmitter; (4) sounder or receiver.

The *galvanic battery* was once used, Daniell's, gravity, Leclanché's, or modified Wollaston's, but now the telegraph companies use dynamos.

The *conductors* are galvanized iron wire or Cu wire or iron coated with copper. Insulated supports are of glass or gutta-percha, which is the best insulating substance known. In large cities the wires covered with gutta-percha or prepared hemp are placed underground in tubes or lead pipes.

Submarine cables consist of a core of seven Cu wires, each 1 mm. in diameter, twisted together and covered with a mixture of tar, resin, and gutta-percha. This insulator proper is coated with hemp, and outside that is a protecting sheath of steel wire, also spun round with hemp.

At the sending station the line is connected with the + pole

of the battery; the current passes to the other station, and if there were a return wire would traverse it to the — pole. But the expense of this second line can be saved by using the earth as a return conductor. It is better than a wire, for it offers no resistance, does not actually return the current, but acts as a reservoir, giving and receiving electric energy. So the end of the conductor at one station and the — pole of the battery at the other are connected with large Cu plates, which are sunk some distance into the earth, or they may be connected with gas- or water-pipes. The circuit may be *open* or *closed*—*open* where pressure on the key completes the circuit, *closed* where a signal is produced when the key is lifted.

The *sender or key* K (Fig. 141) consists of a mahogany base supporting a metal lever, one end of which is kept raised by a spring beneath. The other end of the lever is connected with the line wire. When the key is depressed it strikes an *anvil* connected with the battery, and the current, passing along the line, attracts the armature of some receiver with a click. If the key is held in contact for an instant, it constitutes a dot; if for a longer time, a dash. When the key is not in use the circuit is closed by a lever pushed under the anvil; so a current is passing all the time.

The *receiving* instrument may either be a *register* or a *sounder*. A register consists of an electro-magnet whose armature is provided with a point which indents a tape of paper passing beneath. Clockwork rolls the paper upon a drum, and thus the message can be read from the dots and dashes. Double embossing registers are in common use, by which two separate messages may be registered. Inking registers are also used.

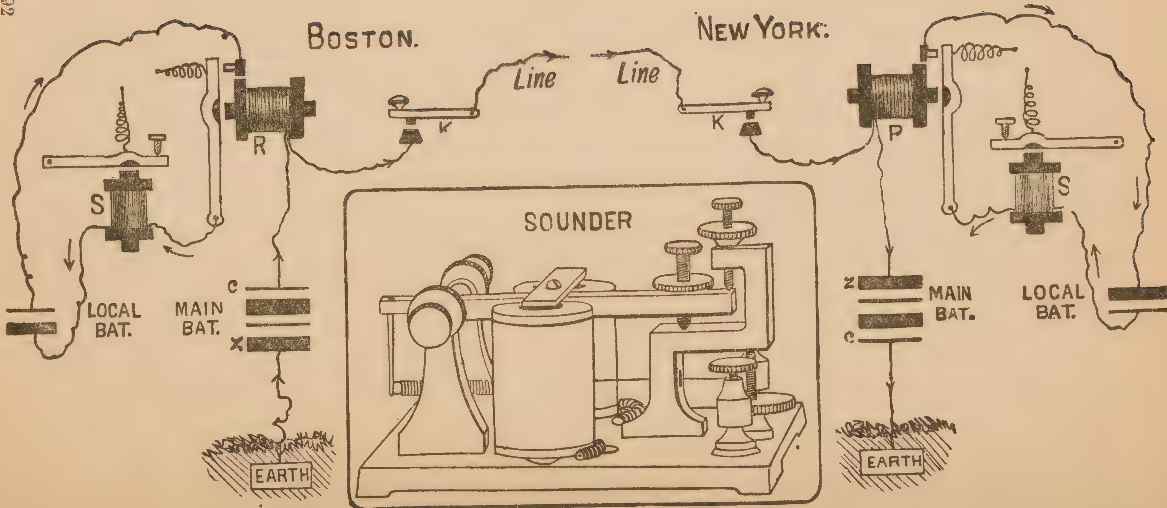
Messages are usually received by sound. The *sounder* (Fig. 141) is practically as the above, only the style of the armature is allowed to click on a brass sounding-piece, and when the current ceases a spring withdraws the armature, and it makes a light click on a screw-point above. A sharp click indicates the beginning of a dot or dash, a light click its termination. A pause following a sharp click is a dash; one following a light click is a space.

What are some of the accessories of a telegraph line?

The *relay*, *repeater*, *lightning arrester*, *ground switch*, and *cut-out*.

On circuits longer than twenty or thirty miles the current may

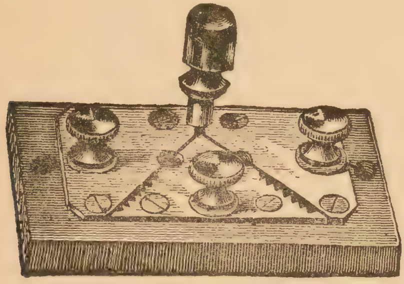
Fig. 141.


BOSTON.
NEW YORK.
Line
Line
K
K
R
P
S
S
LOCAL BAT.
MAIN BAT.
C
Z
MAIN BAT.
Z
C
LOCAL BAT.
EARTH
EARTH
SOUNDER

become so enfeebled as to be unable to work the sounder. A *relay* is necessary; that is a second electro-magnet R (Fig. 141), still in the line current and serving to introduce into the sounder the current of a local battery, which is only used for recording signals. If the message is destined for a more remote place, a powerful battery is substituted for the local one. In this case the relay is called the *repeater*, and the message can be forwarded four or five thousand miles without an operator.

Every time that Boston presses his key the armature in his own office, in the New York office, and at all the way stations falls, and the message can be read at every station. The *cut-out*, *ground switch*, and *lightning arrester* are usually combined, as in Fig. 142.

FIG. 142.



Three brass plates are mounted on an insulating block, the central plate having a row of points on either side. The end plates are connected with the terminals of the line, and the office instruments are placed in circuit between them. The central plate is connected with the earth. When a brass plug is inserted between the end plates, as shown, the office instruments are cut out of the circuit.

If lightning should strike the line anywhere, its high potential would cause it to leap across the points and escape to the earth by the central piece, instead of taking the longer route through the instruments. The direction in which line connections are interrupted can also be determined by inserting the plug between the central plate and an end piece.

The course of a current at the receiving station is first into the lightning conductor, thence into a small galvanometer, indicating the

passage of a current, thence into the office instruments, the key, and next the relay. This establishes connection with the local battery and that works the sounder.

The American Morse code is used in the United States and Canada, but in all other nations of the world the International Morse code is used, established in 1851.

Describe autographic telegraphy?

Autographs, or even photographs, may be transmitted by telegraph. The name or message is written in letters of wax on a strip of tin-foil. At the receiving station is a paper moistened with prussiate of potassium. A needle or iron pen at either station is moved simultaneously by clockwork across the sheet of foil and the K paper. As the current passes the prussiate of K is decomposed, and a continuous blue line is made until the pen at the sending station strikes a line of sealing wax; here there will be a break in the blue line. Each needle is moved down a hair's breadth as it traverses its respective sheet, and the message is received in light letters on a blue ground.

In Elisha Gray's *telautograph* a common lead-pencil writes the message; near its point are fastened two silk cords which connect with the instrument and control the pen at the other end. Sketches, short-hand notes, and business done by mail may be done by wire.

What is to be noted in connection with submarine cables?

The difficulty observed is, that the wires retain a charge by induction after the battery is detached. The cable constitutes an immense Leyden jar, which must first be charged before the current can reach the other end. When communication is first made there is an *arrival wave* followed by a *variable period* till the flow is constant.

Signals are received by a reflecting mirror, Thomson's galvanometer, the motions of the spot of light to the right or left forming the alphabet. Thomson also devised the *siphon recorder*, where ink from a capillary tube makes deflections to the right or left on a paper ribbon. These deflections represent the Morse signals.

Can more than one message be transmitted at a time?

Duplex telegraphy is a means by which messages may be sent simultaneously in opposite directions on one and the same wire. It

was first suggested by Moses Farmer in 1852, but the method of Stearns was not practically adopted into the United States till 1872. A description cannot be given here. Each station is provided with a Morse electro-magnet wound with two sets of wire in opposite directions; one coil is connected with the line and the other with the earth. There is no indication of a message being sent at the sender's instrument; his armature is only attracted by an incoming message. There are the *Stearns system* and the *polar duplex.*

In 1874, Edison and Prescott invented the *quadruplex* telegraph, by which four messages may be transmitted at the same time on the same wire, part going in one direction and part in an opposite direction. It is a combination of the Stearns duplex and polar duplex, and is a practical success. Multiple transmission to an indefinite extent has not yet been realized.

What is Wheatstone's system of rapid transmission?

Transmission by manual manipulation of the key does not exceed 25 to 50 words per minute. A more rapid means is necessary in large offices. Wheatstone's method is related to the manual method about as printing is to writing. The message has first to be prepared by recording it with perforations in a strip of tough paper. It is then passed automatically through the transmitter and received in Morse characters on an inking register at a distant station. 125 to 250 words per minute can be thus transmitted.

CHAPTER XXIX.

VOLTAIC INDUCTION.—ELECTRICAL MACHINES.—TELEPHONE.—THERMO-ELECTRICITY.

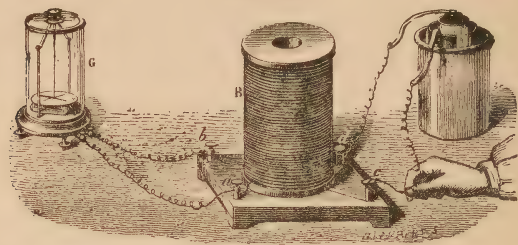
How may induced currents be produced?

We have already noted statical and magnetic induction. Dynamical electricity produces analogous effects. Instantaneous induced currents may be developed in conductors (1) when brought near other conductors traversed by a current, and (2) when brought under the influence of a magnet.

How may induced currents be produced by intermittent ones?

Take a coil of thick insulated Cu wire. Upon this coil wind a second one of considerably greater length of fine Cu wire, but wholly unconnected with the first. The former is the *primary* coil, to be connected with the battery; the latter is the secondary coil, and is connected with the galvanometer. At the moment when the thick wire is traversed by a current (Fig. 143), the galvanometer

FIG. 143.



indicates an induced current in the secondary coil, *inverse* to that in the primary coil. It is only instantaneous, however. At the moment when the current ceases in the primary coil a *direct* induced current is produced.

How may induced currents be produced by continuous ones?

Instead of closing and opening the primary current, we may approach or withdraw it from the secondary coil, as in Fig. 144. On approaching there is an *inverse induced* current; on withdrawing there is a *direct induced* current.

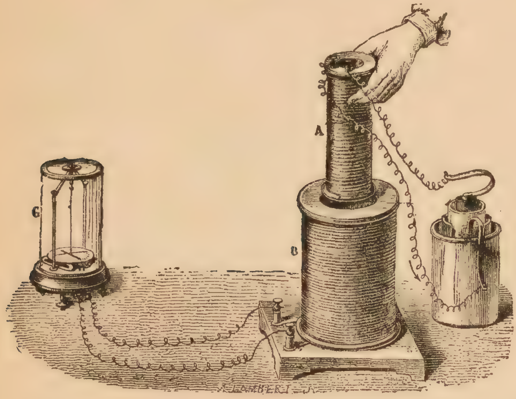
Again, if the intensity of the primary current be varied, we may get the same results—viz. an inverse induced current if the intensity of the primary one increases; direct if it diminishes.

$$\left.\begin{array}{l}\text{A beginning current}\\ \text{An approached current}\\ \text{An increased current}\end{array}\right\}\text{gives an inverse induced current.}$$

$$\left.\begin{array}{l}\text{An ending current}\\ \text{A withdrawn current}\\ \text{A diminished current}\end{array}\right\}\text{gives a direct induced current.}$$

Work has to be done on approaching or withdrawing currents from conductors. Parallel currents in opposite directions repel, and in the same direction attract. So on approaching the primary to the secondary coil, repulsion has to be overcome, as the currents are

FIG. 144.



inverse; on withdrawing, attraction has to be overcome, as both currents are in the same direction.

Always when a current flows through a conductor it is found that the effect of induction is to produce an opposite current in any adjacent parallel conductor. The nature of this action is seen from this diagram (Atkinson):

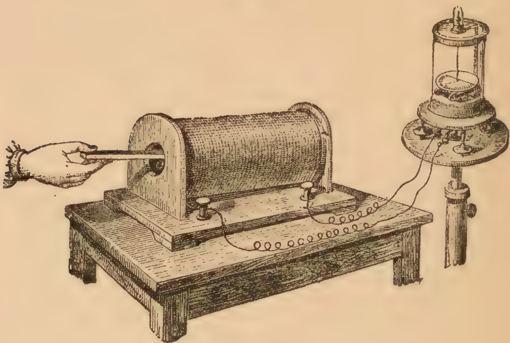
$$(a) + 10 + + + + + + 1.$$
$$(b) - \ 2 - - - - - - - \tfrac{1}{5}.$$

Let (a) be a conductor where the current flows from left to right by virtue of the difference in potential between 10 and 1. (b) is an adjacent parallel conductor. Inductive influence radiates in all directions, and perhaps (b) only receives $\frac{1}{5}$ of the electric force from (a). A + potential of 10 will induce a — potential of 2, and opposite the + 1 will be — $\frac{1}{5}$. As electric movement is from a higher to a lower potential, in (b) it must flow from right to left, opposite to that in (a).

How are currents induced by magnets?

The inductive action of magnets is only an induction of currents, a confirmation of Ampère's theory. Plunge a bar magnet into a bobbin of wire connected with a galvanometer (Fig. 145), and an induced current is produced opposed to the direction of the

FIG. 145.



Ampèrian currents around the end of the magnet. Withdraw the bar, and a direct current is produced.

Or use soft-iron wires as the core of an electro-magnet, and bring a bar magnet into contact with the wires. On approaching or withdrawing the magnet the galvanometer needle will indicate inverse or direct currents.

Again, rotate an electro-magnet in front of a permanent magnet or *vice versâ*, and induced currents are produced. Again, surround a horseshoe permanent magnet with a coil, and pass a soft-iron plate rapidly in front of the poles. The soft iron, becoming magnetic, reacts on the magnet, and alternate induced currents are produced in the wire. The dynamo and all magneto-electric machines involve these principles.

What is the effect of magnets on bodies in motion?

Arago's experiment was to rotate a disk of copper beneath a magnetic needle. The needle will rotate in the same direction as the disk. Induced currents are produced in the metal. Or rotate a horseshoe magnet beneath a disk of copper, and this disk will take

up the rotation. The earth's magnetism can also develop induced currents in metallic bodies in motion.

How may a current induce a current upon itself?

If a closed circuit of many turns of a single wire be traversed by a current and suddenly broken, a perceptible spark is obtained, and a smaller or an inappreciable one when the current is closed. Each coil seems to exert an inductive action on each adjacent coil, in virtue of which a *direct extra* current is produced at the "break," thus strengthening the principal current, and an *inverse extra* current at the "make," diminishing the principal one, and so producing a less spark.

This is analogous to the flow of water in a tube under the influence of gravity. The inertia of the mass retards the current when it begins, but continues it when suddenly interrupted.

Such currents are called *extra* currents, *Henry* currents, or currents of *self-induction.* They occur to a slight extent even in a straight conductor. These two extra currents have the same E.M.F., which is proportional to the strength of the primary current.

Induced currents, though instantaneous, can by their action on their parent currents give rise to new induced currents, and these again to others, producing induced currents of *different orders*, analogous to the multiple image phenomena in plane mirrors. These are also called Henry currents.

What are the properties of induced currents?

Both the direct and inverse are of high potential, and will produce violent physiological, heating, luminous, and chemical effects. They are equal in chemical action, but the inverse does not magnetize or produce shocks.

We have thus seen that induced currents may be produced in five ways: two ways by currents, two ways by magnets, and self-induced currents.

1. Making and breaking current in primary coil;
2. Approaching or withdrawing a continuous current in primary coil;
3. Extra currents, self-induced, at make and break, one coil;
4. Approach or withdrawal of a magnet from a coil;
5. Place soft iron in coil and intermittently magnetize it.

Electrical Machines.

There are three chief varieties:

1. Electro-magnetic machines;
2. Magneto-electric machines;
3. Dynamo-electric machines, or dynamos.

Electro-magnetic machines consist of electro-magnets connected with galvanic batteries, and attracting soft-iron armatures. These constitute one form of the electric motor, but these machines will never be practical, as the cost of Zn so far exceeds that of coal.

The other two varieties, magneto-electric and dynamos, consist essentially of two parts—(1) a revolving electro-magnet, called the *armature*, and (2) a powerful stationary magnet, called the *field magnet*. In magneto-electric machines the field magnet is a permanent one of steel; in dynamos it is an electro-magnet, because more powerful; so in dynamos one electro-magnet, the armature, revolves in front of a second one, the field magnet.

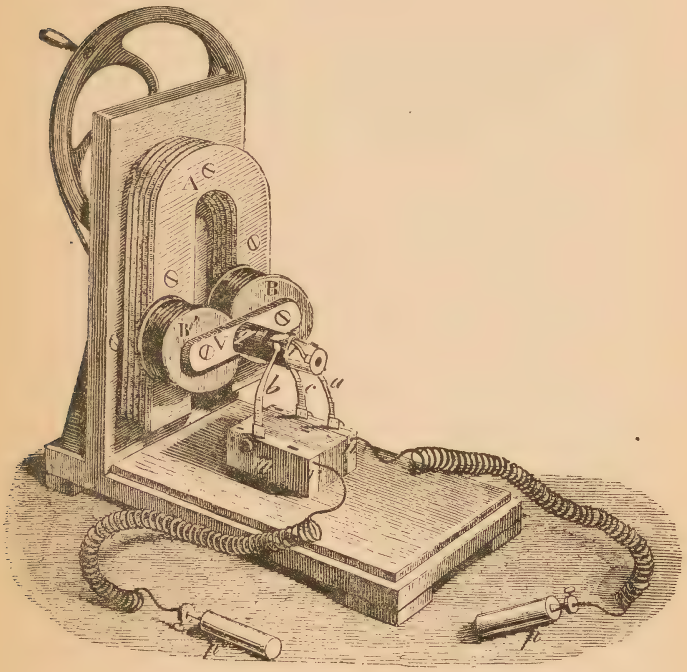
What are some forms of magneto-electric machines?

The first was invented by Paxii in 1833, and improved upon by Saxton and Clarke. As now constructed it is known as Clarke's machine, and consists of a powerful horseshoe magnet A (Fig. 146), which is stationary. In front of it is the electro-magnet B B′, movable about a horizontal axis; it is the armature to the magnet. The wires in the two bobbins are wound in opposite directions, so that the two currents may not neutralize each other, but be of double the E.M.F. that one bobbin would have. The ends of the wires are attached to a copper ferule *q* on the axis. A large quantity of small wire will give high potential, a small quantity of large wire will give low potential. During the first quarter revolution there occurs a separation of poles B B′ from A. This produces currents in both bobbins. During the second quarter revolution the poles are approaching A, and the effect would be to reverse the current, but the polarity of the cores changes because they are approaching new poles, and this double change allows the current to flow as before. At the end of a half revolution, however, there is a reversal of current, as the polarity is unchanged at this point. So during every revolution

there would be a current half the time in one direction and half the time in another.

To secure a constant current, a *commutator* $q\ i$ is placed on the axis, revolving with it. It consists of two half ferules, which

FIG. 146.



become alternately + and — from their connection with the bobbin wires. Springs b and c slide over these pieces, and the ferule against b is always +. As this + ferule rotates, the current having reversed in the coils, it becomes — at spring c. Thus the currents all flow in the same direction through the external circuit, and a direct current is made out of these transient alternating currents.

The *Alliance machine* consisted of ninety-six electro-magnets

mounted on six bronze wheels which rotated between fifty-six steel magnets, and would produce over 53,000 currents per minute.

Siemens' armature (1856) was about the next improvement. Here the wire is wound lengthwise on the core instead of transversely. The core has flanges projecting beyond the central part, and a cross-section resembles the letter H (Fig. 147). These flanges

FIG. 147.

are the armature's poles, and when they are alternately magnetized and demagnetized their induction produces currents alternately + and —. These are adjusted by a commutator at C. Round P passes the band for rotation. This is a very useful compact form, and is easily surrounded by a number of magnets.

Wild's machine consists in substituting a pair of electro-magnets for the steel magnet to produce the magnetic field. These are excited by a small Siemens machine mounted above, consisting of a Siemens armature and a permanent magnet. A Siemens armature is also used below, as well as above, and from this lower one passes the external circuit.

What is the principle of the dynamo?

The magnetism is furnished by the play of the machine itself, and is not obtained from permanent magnets. The essential parts are the *armature*, the *field magnets*, the *commutator*, and the *brushes*. The armature and field magnets are all electro-magnets.

Iron when magnetized retains a little residual magnetism. Siemens and Wheatstone in 1867 discovered that a current can react upon itself, and they proposed to excite the field magnet by the multiplication of this residual, and so dispense with an exciting machine. The rotation of the armature with its slight residual magnetism induces a current in the stationary electro-magnet, and this in turn reacts on the armature, which again increases the strength of the electro-magnet, and so on. The current goes on

increasing with the velocity of rotation, only limited by the heating of wires and bearings and the difficulty of proper insulation. The brushes are the springs for taking up the current; they consist of a number of thin copper plates soldered together at one end.

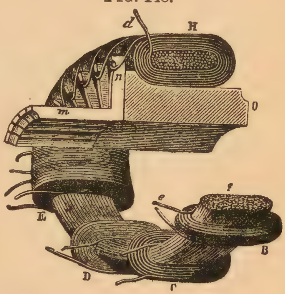
Ladd's machine is substantially that of Wild, with the steel magnet removed. The two armatures are retained; one connected with the field magnet coils, and the other with the external circuit. The two field magnets are placed horizontally, with a Siemens armature at either end. Such a machine is run by steam, and its currents may be commutated or not.

Describe Gramme's armature.

The above machines give a series of intermittent currents resembling waves or the strokes of a pump. Gramme has invented a machine which gives direct and practically continuous currents.

In 1862, Prof. Pacinotti invented armatures in the form of a ring, where coils were wound round an iron core. Gramme in 1870 improved upon this by using a ring made of soft-iron wire (Fig. 148), and entirely covered with coils, B, C, D, etc., the *in* wire of one joined with the *out* wire of the next. This covering does not obstruct the transmission of magnetic force to the core. The improved commutator used in connection consists of eight or more copper knee-plates *mn*, mounted on the armature's axis, parallel to its length. Each plate connects with a coil, there being an equal number of each, and they are insulated from each other by wood, and are attached to a wooden block *o*, mounted on the axis. As currents reverse at each half revolution, a commutator with but two segments produces an intermittent current; if four segments, and if a brush make contact with the approaching segment before breaking contact with a receding one, there is no intermission, but still the current is uneven. With eight or more segments, it becomes practically even.

FIG. 148.



Gramme's machine is magneto-electric, as the above armature

rotates between the poles of a permanent magnet. This magnetizes the core, and that induces currents in the surrounding coils. In one half of the semicircle the currents will all be going in one direction; in the other half in the opposite direction.

Mention other forms of armatures.

The *cylinder* or *drum* armature is a common form, where wire is wound lengthwise on a cylinder, and this cylindrical core consists of a large number of thin sheet-iron disks insulated from each other by tissue-paper. The Weston and Edison armatures are of this class.

There are also *closed-circuit* and *open-circuit* armatures. The former are those wound, like the Gramme, in an endless spiral, connecting with the commutator by radial arms. In the *open-circuit* armature each coil is independent of every other, being connected to two opposite segments of the commutator, which is unconnected with the other coils. This kind is used in the Brush dynamo.

What is the magnetic lag?

The armature core does not become fully magnetized the instant induction occurs, nor fully demagnetized the instant it ceases. This is known as the *magnetic lag*, during which the poles are carried slightly forward in the direction of rotation.

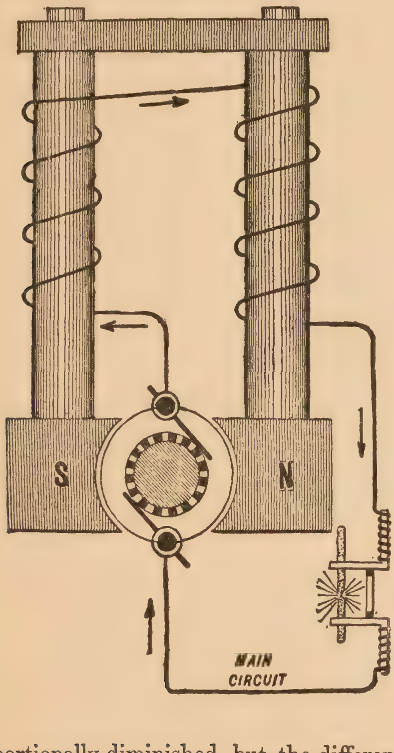
What are the methods of winding field magnets?

Field magnets vary greatly in construction, and constitute the principal part of the framework of each machine. They have massive cores, usually of best cast iron; the advantage of wrought iron does not compensate the extra cost. These terminate at one end in enlarged pole-pieces, which nearly surround the armature, the opposite ends being connected by bolted cross-bars. They are wound with heavy insulated copper wire, which is continuous between the two cores. There are three methods of winding, known as *series*, *shunt*, and *compound*. In the *series* method (Fig. 149) the entire current passes a single route of low resistance, traversing in series the armature, the field magnets, and the external circuit. Variation of resistance at any point affects the entire series.

In the *shunt* method (Fig. 150) the current traverses two routes, dividing at the upper brush in the inverse ratio of the resistance of

each circuit. The main current flows to the right through the coarse wire of the external circuit. A small current of about 1.5% to 20% of the entire volume flows through the shunt of fine wire with which the magnets are wound, and is employed only to excite them. If the resistance of the main circuit is increased, the strength of its

FIG. 149.

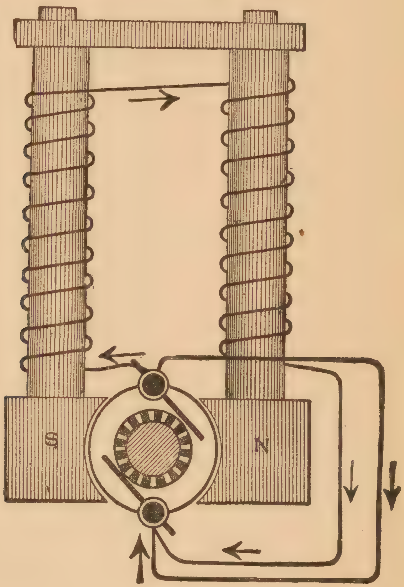


current is proportionally diminished, but the difference of potential between the brushes is increased by this diminished flow. The resistance of the shunt remains constant, so the strength of its current is proportionally increased as that of the external circuit is diminished. This increases the magnetism of the core, and its reac-

tion increases the current strength of both circuits; so an equilibrium is established.

The *compound* winding (Fig. 151) is a combination of series and shunt methods. The shunt wire of high resistance is used to excite the magnets, and a low-resistance wire wound by series method excites them also.

FIG. 150.



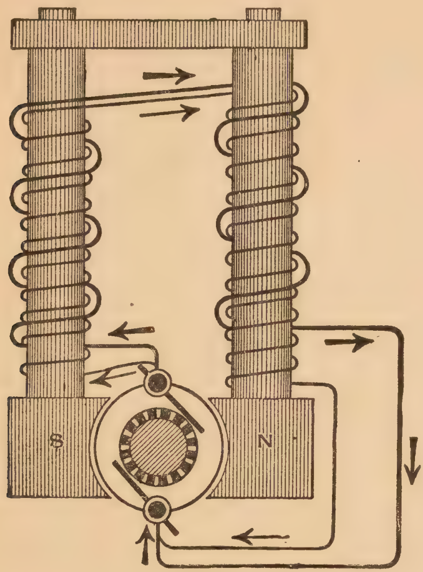
Each of these methods is adapted for a certain work. The series wound machine is most suitable for arc lighting, and the shunt and compound for incandescent lighting. The former requires high E.M.F. and rather small current, while incandescent lighting requires the reverse.

What are some of the different kinds of dynamos?

In maintaining a number of arc lamps in series the resistance is varying according as few or many lights are used. There must be a

constant ratio between the E.M.F. and resistance. A dynamo furnishing an E.M.F. capable of variation is called a *constant-current* dynamo, and is usually series wound. If the work required be to

FIG. 151.



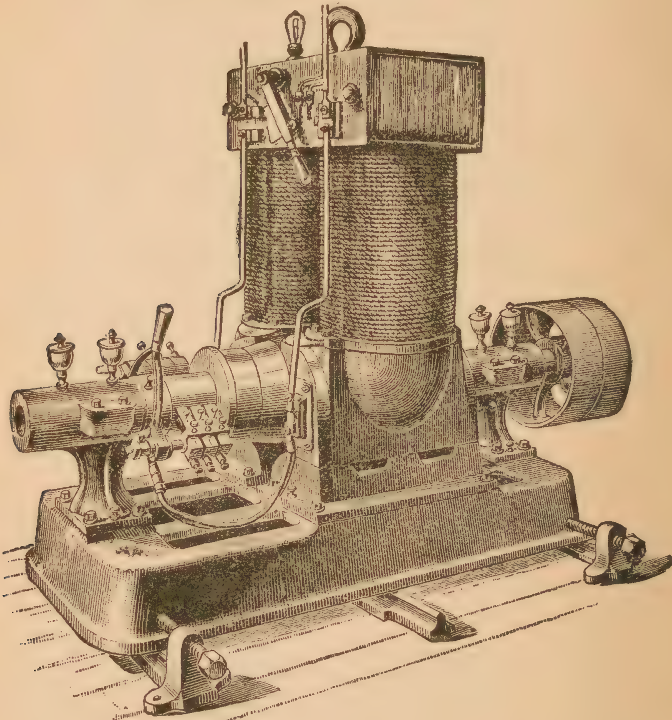
maintain incandescent lamps connected in parallel, the resistance of the main circuit is constant, variation of resistance being confined to the branches. Here the E.M.F. is nearly constant, and a machine for such work is called the *constant-potential* dynamo, and is either shunt or compound wound.

Electric lights can be maintained by either *direct* or *alternating* currents; incandescent lamps usually by the latter. Electro-plating, telegraphy, etc., always by the former.

The Edison dynamo (Fig. 152) is a representative of a direct-current shunt wound machine. He uses it for incandescent lighting. The field magnets are mounted vertically, and rest on massive pole-pieces enclosing the armature below. On the left are shown the

connections of the coils and the projecting terminals of the external circuit. Below is seen the projecting end of the armature with commutator and brushes, the latter attached to a yoke and movable for adjustment of potential. The band wheel is on the right.

FIG. 152.



As examples of the *alternating-current* dynamos are the Gordon and Westinghouse. A direct current for exciting the field magnets in these large alternating dynamos is generally employed. It comes from another small dynamo, and is called *separate excitation.*

Other popular dynamos are the Brush, the Weston (used by the U. S. Lighting Co.), the Siemens, Maxim, etc.

What are the advantages of the alternating-current dynamo?

Here the commutator and its resistance and wasteful sparking are dispensed with, producing a current of much higher potential with less internal resistance than can be obtained from a direct-current dynamo. Such current can be transmitted to a distance by comparatively small wires, and so distribute electric energy at a less cost. The generating station can thus be located on cheap property and furnish a current for use on more expensive property.

Electric Motors.

What is the principle?

The development of the electric motor dates from Oersted in 1819, and has kept pace with that of the electro-magnet. All motors consisted in energizing the electro-magnet by a battery current, producing mechanical action by its attraction and repulsion. Jacobi in 1838 propelled a boat on the Neva at the rate of 3 miles per hour; he used a Daniell battery of 320 cells. In 1851, Page propelled a car on the Washington and Baltimore Railroad at a speed of 19 miles per hour with a 16-horse motor. In 1861, Pacinotti discovered the principle that a motor can be simply a reversed dynamo in which an electro-magnetic current produces mechanical motion, instead of mechanical motion producing a current. An outside current entering the field magnets causes the armature to revolve. This did not receive its first practical application till 1873, by Fontaine, who used the Gramme machine. So a motor and dynamo are identical in principle and construction, and the same machine may be used for either purpose. Generally, two are used together. The first one, or generator, is best a large dynamo run by steam- or water-power. This gives a strong cheap current in preference to an expensive one from Zn. It furnishes electric energy to the second one or motor, which may be small and compact, and this will restore the original mechanical energy with a loss of about 15%.

What are the eddy or Foucault currents?

In both dynamo and motor, currents are induced in the iron core of the armature, flowing in the same direction as those of the coils in the dynamo, and in the opposite direction in the motor. They circulate as eddies in the iron, wasting energy and generating heat.

In the dynamo the useful currents tend to suppress them: in the motor, to increase them. They are regarded as the chief cause of loss of energy in motors. Complete lamination of the core with thin disks and perfect insulation is the remedy.

What are some of the varieties of motors?

Motors may be series, shunt, or compound wound. The Sprague is compound wound. In some the rotation of the armature is reversible. Motors may be direct-current or alternating, the latter requiring two commutators, one for the motor and one for the generator. The Tesla and the Westinghouse-Tesla motors are of this kind.

How is the power distributed to motors?

The parallel system is more practical than the series when a number are operated in shops from one or more large dynamos. Special methods are required for its application to cars. The *trolley system* is most common. Here an insulated wire is suspended above the track, and connection made between it and the motor on each car by a trolley attached to the end of a connecting rod projecting above the car. The direct current is usually employed: it enters the motor by this rod, and returns by a brush or other sliding connection with a wire placed in a conduit between the rails. Or the return current may be through the rails, as they are pretty well insulated on the wooden sleepers. On elevated roads the positive conductor may be connected with a central rail, and the track-rails used for return circuit.

Thermo-magnetic motors are still in the experimental stage.

Describe the inductorium or induction coil.

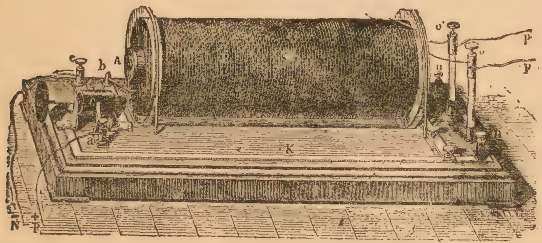
The principle has been alluded to. The coils consist of a bundle of soft-iron wire surrounded by a primary and a secondary coil. The first is connected with a battery, and is alternately opened and closed by a self-acting arrangement. Induced currents in rapid succession are produced in the secondary coil. Three or four Grove cells with this instrument can produce effects equal to those obtained from electric machines or Leyden batteries.

Describe Ruhmkorff's coil.

This is an inductorium of improved construction. The primary coil consists of a few layers of coarse cotton-wound copper wire. It

is about 2 mm. thick and 40 or 50 metres long. Outside this is an insulating cylinder of glass or rubber on which the secondary coil is wound. This is made of fine silk-wound copper wire, $\frac{1}{2}$ or $\frac{1}{5}$ mm. thick, and in Mr. Spottiswoode's machine it was 280 miles long. The thinner and longer, the higher the induced potential. Insulation has to be done with extreme care, and the layers are separated by melted shellac or paraffin. The core is a bundle of wires, to prevent Foucault currents, and they are soldered together so as to be moved in a mass. The coil thus completed (Fig. 153) is mounted on a

FIG. 153.



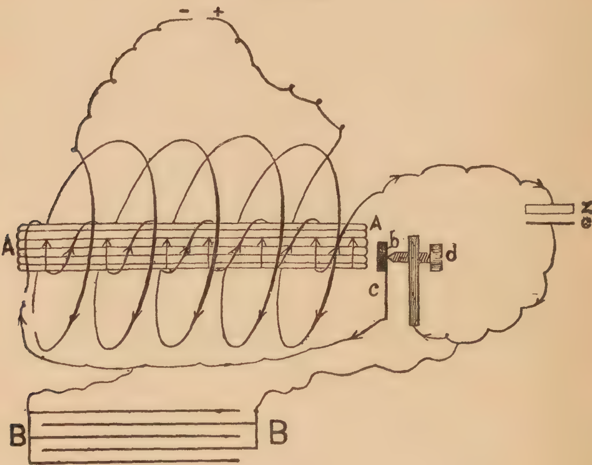
base of wood or hard rubber, in the bottom of which is a *condenser*, consisting of a number of sheets of tin-foil insulated from each other by paraffined paper. The alternate ends of the foils project, so that all oddly numbered sheets are in contact at one end, and all evenly numbered at the other. Each end is connected with the interior terminal of the primary coil, so the condenser is directly in the primary circuit as a sort of expansion of it. It is generally omitted from medical and small coils.

The action of the condenser is to serve as an escape for the direct extra current at time of breaking. The + E. goes to one coating and — E. to the other; they quickly combine by the primary coil, shortening the time of breaking, and producing a shorter and more intense induced current.

The primary current must be constantly interrupted, as secondary currents are only produced at making and breaking. The *interrupter* is placed in the primary circuit, and in small coils consists of a light steel spring called the *vibrator* (Fig. 154). A little hammer *b* presses against the point of the screw *d* and closes the circuit, but

at this moment the soft-iron core A A becomes magnetized and attracts *b*; the circuit is broken, and the iron loses its magnetism. The hammer now springs back and closes the circuit again. This is repeated with great rapidity, giving rise to a series of transient

FIG. 154.



alternating currents in the secondary coil, known as the *Faradic current.* If a weak one is desired, the amplitude of the vibrations is reduced. B B in the figure is a condenser. With large coils the extra current at the break produces sparks sufficient to melt the platinum point and injure the coil by heating. A Hg contact-breaker has been invented. The interrupters may also be operated by clock-work.

The *commutator* or *key* serves to interrupt the battery current or send it in either direction. The course of the current is by wire P from the battery (Fig. 153), thence to the commutator C, and thence by wire *b* through the primary coil. At the other end of the instrument is the interrupter and condenser, not here represented. After them the primary current passes to the Cu plate K, then to C again, and then to the — pole of the battery by wire N. On the right of the figure are wires for the induced currents.

A *sliding core* is often desirable in coils for medical use, to vary the strength of the induced current by varying the magnetism in the primary coil. In this case a small electro-magnet operates the interrupter, instead of the magnetism of the core.

The same object may be accomplished by varying the resistance of the primary circuit. This is done by a *water rheostat.* One terminal is let into a tube of water at the bottom, and the other is attached to the top of a plunger, by which the distance between the terminals, and so the resistance, can be varied. In large coils special construction and winding are required to prevent short circuiting and to reduce what is known as the "Leyden-jar effect," which occurs between the outer coating of the primary coil and inner coating of the secondary.

What are the uses and effects of the induction coil?

The coil is a converter, changing electricity of low potential and large quantity into that of high potential and small quantity—dynamical into statical. The maximum spark obtained from the largest voltaic battery ever constructed was only $\frac{1}{3}$ in. long, while Spottiswoode's great coil with thirty Grove cells gave one $42\frac{1}{2}$ in. in length and perforated glass 3 in. thick.

A coil and battery are used for gas lighting. The wire is interrupted at each burner, and gives short, thick sparks, which pass in series through the escaping gas. The *spark coil* is employed, consisting of the primary coil and core, used with a strong current. The secondary coil and interrupter are dispensed with.

Very curious luminous effects are produced in vacuo and in different vapors. *Geissler's tubes* are of glass filled with various vapors, and then exhausted and sealed. Two platinum wires are soldered into the ends of the tube, and when sparks from a coil pass magnificent lustrous striæ, separated by dark bands, are produced—gyrations and many tints.

In an absolute vacuum there is no electrical discharge; it is a perfect non-conductor.

Dr. Crookes attributes to fluorescence most of these luminous phenomena.

Magnets act on the light of Geissler's tubes, and produce a rotation of induced currents.

Heat is also developed by the induction of powerful magnets on bodies in motion. Considerable force has to be used to rotate a solid disk between the poles of a powerful electro-magnet, and the disk becomes heated. The currents produced and transformed into heat are the *Foucault currents.*

The Telephone.

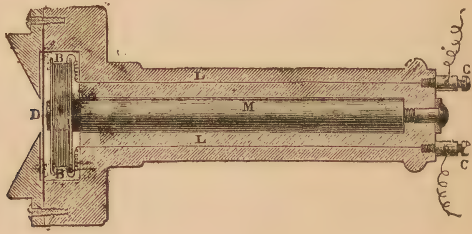
What is its history?

Fifteen years before Bell, Philip Reis in 1861 invented the receiver and transmitter of a telephone. Dolbear also had one of similar construction. Elisha Gray next had a singing telephone and filed a caveat in 1876. The same day Bell filed a caveat for signals: seeing Gray's, he changed his own and got a patent. Claims for priority were made by Gray, Drawbaugh, and Cushman. Bell now holds the monopoly, not only for his own, but for all telephonic communication.

Describe the Bell telephone.

A magnet, spool of wire, and diaphragm are the essentials of the transmitter or receiver. A steel magnet about 4 in. long is enclosed in a wooden case. Around its north pole is fitted a thin flat bobbin, B B, holding about 250 metres of No. 38 Cu wire (Fig. 155), the

Fig. 155.



ends of which appear at the screws C C. One mm. in front of the magnet is a soft sheet-iron diaphragm of about the thickness of letter-paper. There is no galvanic battery. Each instrument may be used as a sender or receiver, but the sender is usually of a different shape, larger and more powerful.

If a coil surround a magnet, we have seen that changes in the

magnetism will induce currents in the wire. In the telephone the magnet and its coil remain fixed: by induction the iron membrane is converted into a magnet. When this vibrates its centre of magnetism continually changes, producing fluctuations in that of the permanent magnet. Thus currents are produced in alternate directions in the coil of wire. These currents, being transmitted in the circuit to a distant coil, alternately attract and cease to attract a corresponding diaphragm. The vibrations of the sender are exactly reproduced at the receiver, and sound is thus transmitted by electricity.

One end of the coil is connected with the earth, and the other with the line. Corresponding connections are made with the corresponding instrument at the distant station. These currents are of exceedingly small force; they would produce 1 cc. of gas in a voltameter in 19 years. It is estimated that not more than $\frac{1}{10000}$ of the mass of sound is reproduced. The sender is really a small dynamo, changing motion into electricity, and the receiver is the motor reversing the process.

Improved transmitters: describe Edison's.

The first great improvement was by Edison—viz. to introduce a carbon button and a battery into the circuit. The voice, instead of generating currents, is only obliged to control a current already generated. Loose contact between any two parts of a circuit increases the resistance and weakens the current. A platinum point is here used on the centre of the disk. A carbon button is pressed gently against it by a spring, all of which are in the circuit. Every vibration of the disk causes a variation in the pressure between these two electrodes, and a corresponding variation in the current resistance. This changes the current strength, and therefore the force with which the receiving magnet pulls its disk. The Edison transmitter and the Bell receiver are often used together.

Another great improvement by Edison was the use of the induction coil. The battery current traverses only a local circuit, including the coil, and the coil produces one of much greater force, possessing all the fluctuations of the primary current.

What is the Blake transmitter?

This is the one most familiar to us, and is employed by the Bell

Co. throughout the United States. It is an improved form of Edison's—a carbon button transmitter. The accessory apparatus is a voltaic cell, the induction coil, and the bell-call. In the upper cabinet, above the transmitter, is the signalling apparatus invented by Gilliland, and connected directly with the line. When we turn the external handle we operate a small hand dynamo or magneto-electric machine. A current is generated which drops an annunciator at the central station. The call-bells are operated by a double-coil electro-magnet, to the armature of which the clapper is attached. In the lower cabinet with the slanting top is a Leclanché cell. This establishes a primary circuit through the parts of the transmitter and through the induction coil contained within it. The secondary circuit of this coil is connected with the line and the earth by its opposite terminals. When the receiver is removed from its hook this lever rises a little and throws the bells, etc. out of the circuit, and closes the battery circuit, which sends a current through the transmitter and primary coil. The weight of the receiver opens the battery circuit, and so prevents exhaustion of the battery when its current is not required.

What is Edison's loud-speaking telephone?

This is a receiver where a spring connected with a vibrating mica disk presses upon a cylinder of chalk. This chalk is moistened with acetate of Hg and caustic soda, and it can be rotated by clockwork. Both the chalk and the spring are in the circuit. Suppose a momentary current from the line passes: the friction between the rotating chalk and spring is lessened by a decomposition, and the mica disk is pulled inward. At other times it is dragged outward, thus producing pulsations and sounds.

How is long-distance telephoning accomplished?

The lines are separated from telegraph lines, and are complete metallic circuits without ground connections. The wire is copper, No. 12. To prevent "cross-talk" where several lines are on the same poles, transpositions are made at regular intervals by crossing the two branches of the line without contact, so that each takes the place of the other on the cross-arms. This neutralizes the induction.

The *Hunning transmitter* and the Bell receiver are used. This

transmitter has a disk of platinum-foil. Behind and parallel with it, at a distance of $\frac{3}{32}$ in., is a second disk of gold-plated brass, and the space between is filled with finely granulated carbon. The battery current passes through the disks and carbon. In front is a metallic funnel-shaped mouth-piece. Lines 600 miles long are now in practical working order.

In Aug., 1893, Prof. Blake of Kansas Univ. succeeded in telephoning from shore to a lightship at sea. A small submarine cable was used, ending upon the ship's anchor; thence the current passed up the uninsulated anchor-chain to the receiver. This promises to be of utmost service in reporting vessels, states of weather, etc.

Describe the microphone.

This was invented by Hughes in 1878, and by it feeble sounds can be reproduced in a telephone receiver. A small carbon rod pointed at both ends is loosely mounted vertically between two carbon supports attached to a thin sounding-board. The terminals of a battery circuit in which a telephone receiver is included are attached to these supports, and the slightest sounds, as the walking of a fly on the sounding-board, are distinctly heard in the receiver. This instrument is too sensitive for ordinary transmission.

Describe the induction balance.

The presence of bullets in a body or differences in weight and composition of metals may be detected by the induction balance. Take two exactly equal primary coils and place them near two exactly equal secondary coils. In the circuit of the primary coils is a battery and a microphone. The secondary coils are joined with a telephone and galvanometer. When the coils are in exact balance, there is silence in the telephone, and the needle is not deflected; but if a piece of metal is introduced into the secondary coil, a sound is at once heard. A milligram of Cu can be heard. A false coin balanced against a genuine one is detected.

What is the tasimeter?

This instrument was invented by Edison, and consists of a piece of carbon forming part of a voltaic circuit and exposed to varying pressure. A galvanometer is also in the circuit. The slightest expansion of any substance compressing the carbon is readily noted

by the needle. The heat of the hand, or, it is said, the presence of a cow in the yard, will affect this instrument.

What is the principle of Bell's photophone?

This instrument transmits articulate speech by the agency of a ray of light. A ray of sunlight falls on the transmitter, which is a wooden box closed at the back by a thin silvered mirror. The vibrating ray from this surface is concentrated upon a *selenium rheostat*, which consists of thin disks of brass and mica and melted Se. This is in a battery circuit with a telephone receiver. The action depends on the alterations in the resistance of Se produced by the action of light, and these alterations produce articulate sounds in the telephone.

How are thermo-electric currents produced?

Thermo-electricity is dynamical, produced by heat. It was first investigated by Seebeck in 1821. When one of the soldered junctions of a metallic circuit is heated, an electric current is produced; if this junction be cooled, an opposite current results.

By experiments, a thermo-electric series is arranged with Bi at one end and Sb and Te at the other. Bi is the + metal and — electrode, so a Bi — Sb couple soldered together corresponds to a Zn — Cu couple in H_2SO_4. The current goes from Bi to Sb across the solder, as it goes from Zn to Cu in the liquid. The intensity of the current is proportional to the difference of T. between the junctions. Hot and cold water in contact can produce a current from hot to cold.

What uses are made of this electricity?

Nobili's thermo-electric pile or battery consists of a series of five couples of Sb and Bi arranged in four vertical columns. The Bi of one series is joined with the Sb of the next, and the free ends with a galvanometer (Fig. 47). These are placed in a box provided with a cone for concentrating heat. Thus arranged, we have the thermo-multiplier of Melloni (Fig. 48). It serves as a most delicate thermometer. The E.M.F. of these currents is very small, but is constant and may be used for telegraphy.

Modern thermo-generators use a Zn-Sb alloy for the + metal and Fe or German silver for the —.

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